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D P Sen Gupta
M H Engineer
V A Shepherd

Remembering Sir J C Bose

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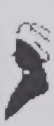
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REMEMBERING SIR J C BOSE

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Acknowledgement

This monograph is the outcome of a Symposium that was arranged at the Indian Institute of Science, Bangalore, on November 28, 2008 to celebrate the 150th birth anniversary of Sir J. C. Bose under the leadership of Professor P. Balaram, the Director of the Indian Institute of Science. The Archives and Publications Cell of the Institute took charge of the organization of the Symposium and set the ball rolling for the publication of this book, assisted by its able secretary Ms. Kavitha Harish.

Professor Sibaji Raha, Director of the Bose Institute, Calcutta, helped by every possible means, providing materials and photographs and even checking through one of the chapters. Professor C. S. Shukre, Director, Bangalore Association for Scientific Education (BASE) initiated a study on Sir J. C. Bose and helped one of the authors in his search of information on the subject. BASE also helped with a couple of drawings and photographs. Mrs Parvathi Bhattacharya, gave her kind permission to use the painting of Jagadish Chandra by Late Bikash Bhattacharya, one of the greatest Indian painters of recent times.

The help and services of other members of the Archives and Publications Cell of the Institute are gratefully acknowledged.

Foreword

I am delighted to have the opportunity to write the foreword of a book on Jagadish Chandra Bose. Jagadish Chandra Bose has been one of my heroes. He is my icon because he created science in India at a time when there was hardly any science. He built instruments when instrumentation was not heard of. He did research on problems related to transmission of radio waves when radios did not exist. He worked on aspects of plant biology which were unknown at that time. Jagadish Chandra Bose is a super example of a very creative intellectual. He was extraordinarily creative the way he did experiments and the way he chose the problems. Even now it surprises me how he ever thought of using a lead sulfide crystal in one of his experiments. Semiconductor solid state physics was not known at that time. In fact, Jagadish Chandra Bose amazes me every time I think of him.

Bengal during the time of Jagadish Chandra Bose was going through the renaissance period. Jagadish Chandra Bose was clearly a renaissance man. Unfortunately, most educated persons and historians have not given Jagadish Chandra Bose his due place in the history of Bengal. I would say that he was one of the greatest personalities of Bengal of the renaissance period. He joins the galaxy of people like Ishwar Chandra Vidyasagar, Raja Ram Mohan Roy and Rabindranath Tagore. To me, he was not only a scientist of great capability but also a person who thought out of the box.

India's first Nobel Prize in science should have gone to Jagadish Chandra Bose. Unfortunately, fate was against it. He was literally cheated out of a Nobel Prize, even though his work was done two years ahead of the work that got the Nobel Prize. Forgetting the Nobel Prize, I feel that he deserves a greater place in the annals of Indian science and in the history of Bengal. It is truly remarkable that we had J.C. Bose in this country. It is even more remarkable that he did everything at a time when there was hardly any formal support for science. He was the first modern experimentalist of India who did outstanding work in the 19th century. I pay my

tribute to this great Indian and to this great scientist on the occasion of his 150th anniversary.

This book brings out the spirit of J.C. Bose and the flavor of the great man. I am delighted that various facets of his personality and contributions have been brought out nicely in the book. I do hope that the book will be read by a large number of people, particularly young people of India.

Professor C. N. R. Rao, F.R.S.
National Research Professor and Honorary President &
Linus Pauling Research Professor
Jawaharlal Nehru Centre for Advanced Scientific Research

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Chapter 1

Jagadish Chandra Bose: The Man and His Time

by D. P. Sen Gupta

1.1. Introduction

Jagadish Chandra was born in Mymensingh, now in Bangladesh, on 30th November 1858. His ancestors hailed from the district Bikrampur, close to Dhaka, the capital of the present Bangladesh, earlier referred to as East Bengal, and later as East Pakistan, after the partition of India in 1947. It was in the year 1971, that the language proud people from East Pakistan fought their way to freedom and Bangladesh was born.

People from the eastern part of the undivided Bengal have been great fighters for their rights and people from the Bikrampur area have also been known for their scholarship. In fact the word "Bikram" in Bengali (Vikram in Sanskrit) means valour which the first authentic biographer of Bose, Patrick Geddes,[1] the Scottish polymath, attributes to the people of that region for the incessant fights they had to put up, defending themselves against the dacoits who used to row long and narrow boats, at high speed down the great rivers of Bengal and invade the villagers in the cover of darkness.

A large number of Sanskrit schools (called "Toles") thrived there in early years and a number of Buddhist monasteries were set up during the 7th to 13th centuries. The famous Buddhist monk Atish (Dipankar) who went to Tibet to spread Buddhism came from this region. A large observatory is also known to have existed in Bikrampur. These account for the relatively high literacy in early days and a distinct flare for scholarship even today amongst the people of this region.

Bengal was first divided by the British in 1905 since India's freedom movement, rooted deeply in Bengal, had already become too hot for their comfort. It was later re-united when the division could not be sustained because of the loud and at times violent protests from both sides of the

Fig. 1. Jagadish Chandra Bose.

divided Bengal. There was an unmistakable cultural divide amongst the people of the two regions. People from Kolkata symbolizing the West Bengal, were soft-spoken and very proud of their cultural heritage, referred to the people from the east as ***Bangal***, in a disparaging manner and made fun of the east Bengal accent. Jagadish was self-conscious of his east Bengal accent to the very end.[2] The people from the east, although eager to emulate the Kolkata standard, became somewhat defensive as a result. The partition of Bengal in 1947 and the huge migration of population to the west from east Bengal have washed away this division to some extent but not entirely.

1.2. Early Years and His Father's Influence

Jagadish was born to a reasonably affluent family. His father, Bhagaban Chandra Bose, was a Deputy magistrate, posted in the district of

Mymensingh. He had embraced the Brahmo religion which is a monistic, casteless religion based on the Upanishads. His wife Bamasundari Debi, was however, an orthodox and a reasonably upper caste, non-Brahmin (Kayastha) Hindu who used to practice the usual Hindu rituals. Jagadish was brought up in a diverse religious ambience. Jagadish had five sisters. His only brother died at the age of ten, leaving his parents, particularly his mother greatly distraught. Young deaths were not uncommon in those days, but the presence of other children, in a usually large family, and deep religious faith, helped the acceptance of such deaths, however painful. Bhagaban Chandra's parents lived with their son and were practicing Hindus.

Jagadish's father was an extraordinary person. He was highly-educated and loved science. Although well-placed Indians in those days aspired for their sons careers in the Civil Service or in the legal profession, Bhagaban Chandra wanted his son to become a scientist or take up the medical profession.

His courage and strength were legendary.[1] He was also a very kind person. Once a dacoit, sentenced to prison by Bhagaban Chandra himself, came to him on his release after six years in jail and sought a job since, as he said, no one would employ an ex-dacoit.

Bhagaban Chandra not only employed him but also put young Jagadish, 4 years of age, in his charge, giving him the responsibility to keep him company and carry him to and from school on his shoulders. That was when

Fig. 2. Bhagaban Chandra Bose (by Mr. B. G. Gujjarappa, courtesy, Bangalore Association for Science education).

Fig. 3. Bamasundari Debi (by Mr. B. G. Gujjarappa, courtesy, Bangalore Association for Science education).

little Jagadish got to hear many thrilling stories. In real life, one night, when the entire Bose family was out on a vacation in a big country boat, the ex-dacoit, who was traveling with them, noticed in the middle of the night that a number of speed boats were converging on them. He instantly knew that it was a gang of dacoits coming to plunder their boat. He got on to the top of the boat and yelled a signal that only the dacoits in that area would understand. The invaders turned round their boats and beat a hasty retreat.

Bhagaban Chandra was a great philanthropist and he embarked on many ventures in order to alleviate the conditions of the poor. He started the first "People's Bank" for the poor and this later gave rise to "Cooperative Banks". The bank turned out to be a big success. Bhagaban Chandra could have made a lot of money if he wanted to. But he gave away most of his shares in the bank to poor relatives.

Bhagaban Chandra had realized that Indians lacked entrepreneurship and the British were making huge sums of money out of India with almost no competition from the native population. He invested his savings to buy a very large forest land in Assam and started growing tea. He launched into several other ventures but over-work took a toll of his health and he had to go on medical leave for a couple of years.

Most of his ventures failed and a debt-ridden Bhagaban Chandra almost faced penury. (Most of his ventures turned successful later but he did not get

to see their success. Most of the properties had anyway been sold off by then.) As we shall see later, it was Jagadish Chandra who repaid the entire debt of his father in due course, largely from his own resources and yet he had, all along his life, the greatest respect for his father, who was described by some as a failure.

In an article published in the *Modern Review*, 1917, based on a lecture which Jagadish Chandra delivered at the invitation of the President and the Committee of the Faridpore Industrial exhibition to speak on his father, this is what Jagadish Chandra had to say in conclusion:

> *"To me, his life had been one of blessing and daily thanksgiving. Nevertheless, everyone had said that he wrecked his life which was meant for far greater things. Few realize that out of the skeletons of myriad lives, vast continents have been built. It is on the wreck of a life like his and of many such lives that will be built the Greater India yet to be. We do not know why it should be so, but we do know that the Mother Earth is hungry for sacrifice."*

Bhagaban Chandra used to arrange a number of cultural and sports events for the rural folks. *Jatras* or folk theatres were very popular. It was in the *Jatras* that young Jagadish came to watch India's great epics, the Ramayana and the Mahabharata. Out of all the characters in the Mahabharata, it was Karna who was the illegitimate son of Kunti, the mother of the Pandavas, who fascinated Jagadish. Abandoned by his mother at his birth and raised by the wife of a charioteer, Karna fought with the Kauravas against his brothers because Dronacharya, who belonged to the Kauravas, taught him archery and Duryadhana, the king of the Kauravas, had offered him royal status. There was only one person in the entire Pandava clan who could match Karna in archery, and that was Arjuna, one of Kunti's five sons who were raised as princes. Kunti came to beg of Karna to join the Pandavas and offered to make him the king of the Pandavas before the famous fight between Karna and Arjuna was to take place. Karna refused her offer and gave his life in an unfair battle. Karna's life was one of suffering when he could have had a kingdom. But loyalty was what mattered to Karna. Jagadish Chandra, in his subconscious, may have identified his father with Karna and he himself aspired and tried to live a life without ever compromising his loyalty to his nation.

Bhagaban Chandra set up a vernacular school (Pathshala) where children of farmers, fishermen and laborers would study in Bengali. He sent Jagadish to this school rather than to an English school as was customary in upper

middle class families. His objectives were clear. He wanted Jagadish to be trained in his mother tongue and grow deep roots in the soil of Bengal. Jagadish grew up with poor children of all castes and creeds who were mainly poor. Speaking about his schooling and also of his mother in a conference in Bikrampur in 1915, Bose said:

> *"At that time, sending children to English schools was an aristocratic status symbol. In the vernacular school, to which I was sent, the son of the Muslim attendant of my father sat on my right side, and the son of a fisherman sat on my left. They were my playmates. I listened spellbound to their stories of birds, animals and aquatic creatures. Perhaps these stories created in my mind a keen interest in investigating the workings of Nature. When I returned home from school accompanied by my school fellows, my mother welcomed and fed all of us without discrimination. Although she was an orthodox old-fashioned lady, she never considered herself guilty of impiety by treating these "untouchables" as her own children. It was because of my childhood friendship with them that I could never feel that there were "creatures" that might be labeled "low caste". I never realized that there existed a "problem" common to the two communities, Hindus and Muslims."*

When Jagadish was about six years old, his father bought him a pony and he quickly learnt to ride it. Once he had gone to see a horse race and some of the spectators, out of sheer fun, goaded the little boy to join the race. Jagadish raced his pony, precariously hanging from it, right to the end, badly bruised. But he would not give up. And that was Jagadish right till the end of his life. He would not give up easily. Jagadish was almost eleven years old when he was sent to Calcutta to study English. By now, his father had been transferred to Burdwan in West Bengal, as an Assistant Commissioner. After three months in Hare school, he joined St. Xavier's, an excellent school and College set up by Belgian Jesuits. The school was almost exclusively for English boys and Jagadish Chandra with his inadequate English and largely country background felt ill-at-ease in their company, and as often happens to a new comer, Jagadish was teased and later challenged to a fight with the class champion. Jagadish fought and was badly beaten. The fight seemed to be over in favor of the class champion when Jagadish, with a sudden burst of energy, pounced on his adversary and knocked him down. Hence, he was hailed as the victor and acquired full rights of freemanship but not their friendship because he was a native and not in the same class. Jagadish was essentially a loner in his school and in the hostel where he was lodged.[1]

1.3. Emergence of Western Education in Bengal

It may be worthwhile to discuss in this context the status of science education then prevailing in India and to what extent Jagadish was exposed to western science before he left for England.

In general, science education in India was at a primitive stage or non-existent. It was not in the interest of the colonials of the East India Company to introduce Western science into a colony any more than was necessary for them to carry out surveys and geological explorations to measure the resources that they could exploit. The board of Governors of the East India Company would readily accept proposals that had rich financial returns and would help the colonizing process.[3]

According to Arnold,[4] "The East India Company's Board of Directors in London exercised a commanding position in relation to science in India ... and its servants enjoyed a near monopoly over western science activities in India".

It is unfortunate that the status of exact sciences in India which was equal to that of Europe till the end of the 16th century, if not better in some respects, languished and entered a state of utter stagnation while western science surged ahead in Europe.[3] According to the great chemist Professor P. C. Ray, a contemporary of J. C. Bose, the decay in Indian science had much to do with casteism since people belonging to higher caste were not supposed to work or dirty their hands.[5] Pedantry replaced scholarship.

The country was generally passing through a stagnant phase when Raja Rammohan Ray appeared like a mighty river, as described by Tagore, rejuvenating life along its banks. There were others such as William Carey, Rev. Alexander Duff, and David Hare, to name a few, who helped in trying to introduce Western education in India.

The first educational Institute established by the East India Company was in 1780 by Warren Hastings. It was the Calcutta Muhammadan College, a madrasa, to impart English education.

The Asiatic Society was set up in 1781 at the initiative of Sir William Jones and this was followed by the establishment of a Sanskrit college in Varanasi in 1793.

The British Parliament, in renewing the charter of the East India Company in 1813, introduced a section which pledged the Government of India to set apart Rs I lakh for educating people residing in the British territories in India both for reviving as well as improving the indigenous system of education and also for the promotion of knowledge in sciences among

them. The allotment could hardly be called generous and would clearly indicate British apathy towards promoting western science in India.

Anxious that this meager amount of money would be utilized only for the revival of an ancient system of education, Rammohan in his letter (1823) to Lord Amherst wrote:

> *"But as the improvement of the native population is the object of the Government, it will consequently promote a more liberal and enlightened system of instruction embracing Mathematics, Natural philosophy, Chemistry, and Anatomy with other sciences which may be accomplished with the sums proposed, by employing a few gentlemen of talent, learning and education and providing a college furnished with necessary books, instruments and other apparatus."*

Rammohan's letter was passed on to the Committee of Public Instruction, but it met with a cold response.[6] Dwarakanath Tagore, grandfather of Rabindranath Tagore, the poet, supported Rammohan Ray as did the great educationist David Hare and a few others who helped the foundation of the Hindu College in 1817 to promote a liberal education. The Hindu College was renamed Presidency College in 1855. There were then two distinct groups among the Indians and the British. One group favored what was called Anglicism and the other favoured Orientalism.

Lord Amherst left India in 1828 and was replaced by Lord William Bentinck who favored Anglicism. It was the Minute' of Macaulay (1835), described succinctly by DasGupta[6] as a "mixture of compelling reason, infuriating cockiness, blatant prejudice, ignorance and evangelical fervor which has the power to both command respect and profoundly offend", recommended that the British objective should be to form "a class of persons, Indian in blood and colour but English in taste, in opinions in morals and in intellect". The recommendation of Macaulay and the resolution of Bentinck sealed the fate in favor of Anglicism and the knowledge of English was made compulsory for those who aspired to a high order of education. The Bengali Aristocracy, meanwhile, was not sitting idle. With their relentless efforts, the Medical school was set up in Calcutta in 1835. Western science began to trickle in through medical education.

1.4. British Attitude Towards Higher Education in India

Although it was not the intention of the British authorities, a number of liberal-minded English educationists and Christian missionaries had begun

to set up schools and colleges and the St. Xavier's College where Jagadish Chandra was educated was one such school and college referred to earlier. It was however, following the Wood dispatch, that the decision was made to set up the Universities of Calcutta, Madras and Bombay.

Sir Charles Wood's correspondence with Lord Dalhousie gives a clear idea of the British attitude towards higher education in India. It was believed that, "Education would be fatal to British rule". A journal enquired, as to "whether in our generous enthusiasm in the cause of Indian education, are we not rapidly annihilating the superiority which constitutes the tenure of our empire, and preparing by our efforts, our own political extinction in India".[7] But Wood felt that British administration in India could be strengthened if it could utilize the services of educated natives to impart higher education to them by establishing Universities. He, however, had his apprehensions. "If they become intelligent through education, they become dangerous" and Wood felt that it would be better to direct educational efforts to general education.

"To have educated natives with University education would be", according to Wood, "... the easiest step ... I do not say the most useful, for carrying out the British India administration". Wood did not have many misgivings about Bombay and Madras, but was not keen on having a University in Calcutta. But Dalhousie was keen on setting up the Universities in all three cities and Wood appears to have yielded. But with regard to providing scholarships, this is what Wood wrote[8]:

> *"I care very little about teaching Hindus to read Bacon and to be examined as we should be for honours at Oxford. I have no objection to their acquiring that education but I am against paying them for acquiring it as we do in government schools. ... these highly educated natives are likely to be a very discontented class unless they are employed and we cannot find employment for them all."*

He wrote again[9]:

> *"If they choose to educate themselves, well and good, but I am against providing our future detractors, opponents and grumblers."*

Dalhousie did not fully agree with Wood and he was largely responsible for continuing senior scholarships and setting up the University of Calcutta which was founded on 24th January, 1857.[10]

The preamble of the University Act stated — "Better encouragement of Her Majesty's subjects of all classes and denominations, ... in the pursuit of

a regular and liberal course of education and for the purpose of ascertaining by means of examination the persons who have acquired proficiency in different branches of literature, science and art and/or rewarding them by academic degrees".

The preamble seemed noble in its objective and it helped a number of bright and motivated students to be exposed to western education and to some extent to western science. (Wood's apprehensions were not belied. The belligerence that the British faced in Bengal, which led to the partition of Bengal in 1905, referred to earlier, took shape in the minds of those who had received University education.)

It may not be irrelevant in this context to refer to the Bengal renaissance that took place during the 19th and early 20th century, of which Jagadish Chandra Bose was a product and later came to be one of the flag-bearers in the front line. Was the Bengal renaissance the product of British University education in India? Not really.

The Bengal renaissance that took place during this period, enriched as it must have been by exposure to western culture, was not encouraged by the University education which was influenced by Macaulay's despise for Indian literature, heritage and culture, and his unshaken view and that of his followers, that western education represented the triumph of reason over barbarism.

The renaissance took place when Indians of great mental abilities rediscovered their own heritage, helped to a significant extent by the western angle of vision.[10]

Raja Rammohan Ray, Iswar Chandra Vidyasagar, Madhusudan Datta, Bankim Chandra Chattopadhya, Jagadish Chandra Bose, Rabindranath Tagore, Swami Vivekananda, Asutosh Mookherjee, Sri Aurobindo, were some of the renaissance men with great minds who had deep roots in the culture and philosophy of India from where they drew their sap and sustenance. Western light helped the photosynthesis to a considerable extent.

There were of course exceptions, especially among philosophers and religious leaders. The influence of Sri Ramakrishna, the great mystic, on some of the renaissance men was profound but he himself had no exposure to Western education. Jagadish Chandra was trained in high-level western science. But his deep convictions in Indian philosophy possibly motivated him to take mental leaps to arrive at some of his scientific conclusions discussed later in the chapter. Not that all his conclusions stood the test of time, but they appeared to offer experimental evidence to some of the Upanishadic ideas and hence their tremendous appeal to the Indian intelligentsia of his time.

1.5. Jagadish's Training in Western Science

British attitude towards Indian education underwent a slow change over the years. The funds allotted were still restricted; schools and colleges could hardly afford a laboratory. Hindu College which became the Presidency College was an exception. It was completely taken over by the Government and consumed the lion's share of the limited funds allotted. St. Xavier's College was also an exception. (These two colleges still continue to be the best colleges of West Bengal.) It was here that a good Physics laboratory was set up in 1866 under the direct supervision and guidance of Father Lafont who had a considerable influence on Jagadish. Incidentally, there was another eminent scientist, Pramatha Nath Bose, senior to Jagadish, who was inspired by Father Eugene Lafont (1837–1908) to go for higher education in science. The quality of science education offered by the Belgian Jesuit teachers was far superior to that offered by their British equivalent and St. Xavier's College came to be known as the best in the country at that time.[7]

A very brief account of Father Lafont, who had a profound influence on Jagadish, is called for. He is remembered as the "Father of science in Bengal". He was trained in Philosophy and the natural sciences and had arrived in Calcutta towards the end of 1865. He was the Rector of St. Xavier's College when Jagadish Bose joined in 1875. Father Lafont, had by now become a very popular science expositor. "Science was in the air and people from all walks of life used to come to listen to the lecture series of Father Lafont who used to cover topics like Dalton's atomic theory and show some experiments, illustrating the general principles of matter .... Throughout the series, the gentlemen were most assiduous and punctual in their attendance, notwithstanding the rain and lightning".[7]

At the initiative of Father Lafont, Alexander Pedler (Professor of Chemistry at Presidency College) and Dr. Mahendra Lal Sircar (who in 1876 founded the IACS, Indian Association for the Cultivation of Science where C. V. Raman carried out his researches that led to the discovery of the Raman effect and the Nobel Prize for Raman), the Syndicate of Calcutta University decided in 1872, to divide the BA degree into two streams, "A" course that was entirely literary and the "B" course that had Mathematics, Inorganic Chemistry, Geography and English as compulsory subjects and one optional paper out of Physics, Zoology, Botany and Geology. Brighter students usually opted for the "B" stream which was more popular than the "A" course. Jagadish was persuaded by Father Lafont to study Physics and he passed his BA in the science stream in 1879 and was placed in second class.[11] There was

Fig. 4. St. Xavier's College as it is today.

Fig. 5. Father Lafont.

very little scope, if at all, in India to pursue further studies in science in India at that time. (It was Sir Asutosh Mookherjee (1865–1925), a great mathematician, a lawyer, and the Vice-Chancellor of Calcutta University (1905–1923) who set up the Science College, in Calcutta, helped by big donations from

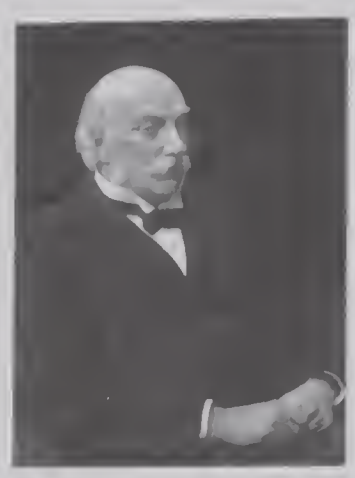

Fig. 6. Lord RayLeigh.

fellow lawyers like Taraknath Palit and Rashbehary Ghosh, for post-graduate studies. With S. N. Bose, Meghnad Saha, S. K. Mitra as lecturers and C. V. Raman as the Palit Professor, the Physics department took off (1916). Incidentally, S. N. Bose, Saha and Mitra were all students of J. C. Bose at Presidency College).

Jagadish was keen to go to England but two problems arose. Jagadish's mother, having already lost a son when he was 10 years old, could not bear to part with her only surviving son on an uncertain voyage to an unknown land. Besides, the financial condition of the family would hardly permit the cost of his journey and studies abroad. Jagadish understood this and decided to stay back. It was at this point that Bamasundari Debi, the mother of Jagadish, took a bold decision that changed the life of Jagadish, and to a great extent the future of science in India. She not only gave her consent but even offered her ornaments if required, to pay for his journey and studies in England. Jagadish left for England. Almost throughout his journey, Jagadish was afflicted by high fever which caused considerable anxiety to his co-passengers. Some were even worried whether he would live to reach the shores of England. The fever was later diagnosed as Kala azar for which no treatment existed in those days. On his arrival, he was admitted to medical study in London but repeated occurrence of fever made it virtually impossible for him to pursue his medical studies and Jagadish was advised to study science.

Jagadish won a scholarship to study in Christ's College, Cambridge, and his life took a distinct turn. If he had not contracted the fever on his

hunting trip to Assam, Jagadish would not have kala azar and in all probability would have completed his medical course and returned to India. Physics and plant physiology would have been poorer for it.

Christ's College was the first college in Cambridge to admit Indians. Ananda Mohan Bose, the first Indian Wrangler, who married Jagadish's eldest sister, was a brilliant mathematician and a famous barrister who preceded Jagadish to Christ's College and so did Justice Syed Mahmud.

While in Cambridge, Jagadish kept having the bouts of fever. This was when he decided to take up rowing, a common sport in Cambridge. His health distinctly improved. At Cambridge, he came directly under the tutelage of great teachers such as Lord Rayleigh, who, a distinguished physicist, got the Nobel Prize for inventing argon, and also Francis Darwin, the son of Charles Darwin, Sir James Dewar and Sydney Vines the great physiologist.

Jagadish obtained his Tripos in Natural Sciences in Physics, Chemistry and Botany. He also obtained a degree from the London University before he decided to return to India, after four years (1881–1885).

Anandamohan Bose's old acquaintance, Professor Fawcet, the economist and then Postmaster General, wrote a letter to his friend Lord Ripon, the Viceroy of India, introducing Bose. Bose, on his return to India, met Ripon at Simla.

1.6. Coming Home

Jagadish was very kindly received by the Viceroy, who was obviously impressed by the bright young man armed with three degrees.

On reaching Calcutta, Bose called on Sir Alfred Croft, the Director of Public Instruction (D.P.I.), who had already received, through the Government of Bengal, a letter from Lord Ripon, recommending Bose to them for an appointment. The Director was none too pleased and told Jagadish, "I am usually approached from below, not from above". He said that the best he could do for Jagadish was to offer him Provincial service and not the Imperial Educational Service (I.E.S.) which was almost always reserved for Europeans. The reason was simple since there was a firm conviction amongst the British administrators that the Indian minds were incapable of comprehending exact sciences, let alone train students. Bose refused to accept Provincial service. Lord Ripon, noticing that Bose's name had not featured in the gazette, sent a stiff note to the D.P.I., who had no choice but to offer him a position in the Education service. Bose was appointed as Officiating Professor of Physics at Presidency College, much to

the annoyance of C. H. Tawney, the principal of Presidency College. His salary was, however, fixed at less than half of what English Professors would receive for the same position.

Jagadish accepted the job but decided to put up a fight. He started working full-time, as best as he possibly could, teaching Physics to his students, arranging experiments with the limited resources available, but refused to accept his pay cheques.

By now, Jagadish was married. Family fortune was at its lowest ebb, riddled in debts owing to the so-called misadventures of Jagadish's father, referred to earlier. Properties were sold. Jagadish often lived with one of his five sisters. But Jagadish would not give up. It was not his fight for personal grievances. It was clearly a fight of an Indian against the naked discriminatory policies of the British rulers in India. This spirit of "obstinacy", not uncommon among people of the Eastern part of Bengal, also made them great freedom fighters, first against the British and next against Pakistan. We shall repeatedly notice this trait in Bose who had to fight almost all his life against a few physiologists who refused to accept an oriental physicist in their midst.

Bose won his fight. Appreciating his commitment to teaching, his ability to maintain discipline amongst students and most importantly, his courage to stand up for what was right, earned the respect of Principal Tawney and the Director of Public Instruction, Alfred Croft who arranged to raise his salary on a par with that of an English Professor, making his position permanent. Jagadish was paid in retrospective effect, three years salary that he had not collected. His adversaries, the Principal and the D.P.I became his friends. Jagadish realized more than ever before that the best way to get on with an Englishman was to stand up to him.[1]

Jagadish used the money that he received in lump sum to repay the creditors of his father. It is said that some of the creditors were so touched to see the efforts being made by the son to clear his father's debts that they offered to write off some of the debts. Bose politely declined the offer and eventually cleared all the debts of his father. By now, Bhagaban Chandra's health was failing and he lived only two years after he felt he was free from all his debts (1892). His wife followed him two years later (1894).

1.7. Marriage

A brief reference to Jagadish's wife may be relevant at this point. Jagadish got married to Abala Das, the daughter of Durgamohan Das and Brahmomayee

Fig. 7. Presidency College as it is now.

Debi. She was born in Barisal (a town now in Bangladesh) on 8th August 1865. When Abala was five years old, Durgamohan shifted to Calcutta. He was a great social reformer, worked very hard to spread the Brahmo religion and took a pioneering role in propagating women's education.

Among women in those years, it was Sarala Debi, the elder sister of Abala, who was the first one to prepare for the Entrance examination but she was married before she could sit for the examination. Subarnaprabha Bose (one of the sisters of Jagadish Chandra) was among the three girls who passed the Entrance examination in 1880 and Abala Das was among the third batch of girls who passed this examination. She joined Bethune College and applied for permission to study medicine. Her application was turned down since Calcutta University had no provision to admit women to study medicine. The refusal caused quite a stir among the intelligentsia of Calcutta and Calcutta University sponsored Abala to study medicine at Madras University with a scholarship of Rs 20.

(This is comparable to the situation when Marie Curie, around the same time, having been refused permission to pursue higher studies in

Fig. 8. Abala Bose.

Poland under the Russian Czars, had to go to Paris and live in the direst poverty to carry on her studies.) But Abala was better off with her scholarship and lived with a non-Indian family in Madras. Abala completed a course of two years but she got married to Jagadish on 27th February 1887 when Jagadish was 29 years old and Abala, nearly 22 years of age. It may be noted in this context that compared to others in that generation in India, they got married somewhat late. Both were Brahmos and greatly emancipated compared to orthodox Hindus.

After her marriage, Abala adopted herself to the Bose family, taking care of the elderly parents of Jagadish. She not only accepted the near poverty of the Bose family at that time, but stood solidly behind the resolution of Jagadish not to accept the salary referred to earlier.[12] Their only child died at birth.

In the year 1910, she became the secretary of Brahmo Girls' School and continued in this position till 1936. With utmost efficiency, she transformed the school which came to be known as one of the best schools of Calcutta which has produced a number of highly illustrious women.

During her visits to Europe and Japan with her husband, she studied the status of female education and was inspired by the rapid advancement of

women's education in different countries. On her return, she had extensive discussions with different people of similar concern and in 1919, set up a committee for women's education. With the help of people like Chittaranjan Das, the celebrated barrister of Calcutta High Court (who gave up everything he had in service of the nation and earned the title of "Deshbondhu", (Nation's friend) and that is how he is affectionately remembered even today), she set up eleven schools for girls. In 1926, she set up schools for vocational training for women. Along with all this work she was always by the side of Jagadish and was a constant inspiration for him.[12]

1.8. Turning to Research

The 36th birthday of Jagadish in 1894, the year in which his mother passed away, was a turning point in his life. Jagadish had so far been working diligently, teaching students, examining papers, duties normally expected of a Professor in those days. His only Indian companion in Presidency College in those days was Dr. Prafulla Chandra Ray, referred to as Acharya P. C. Ray, a chemist of repute who set up the Bengal Chemical and Pharmaceutical Works as a challenge to British Chemical Companies that were inundating the Indian market with their products.

Jagadish wondered whether he should simply continue the way he had been asked to, to be a science teacher or establish himself as a scientist, doing research. Abala Bose supported him and urged him to become a scientist and not be just a science teacher.

As you enter Presidency College, through the crowded book stalls of today, turn right and go up about three steps and look right. There is a small room and this is where Jagadish Bose worked. He decided to turn this into his laboratory. He was better off now, having repaid his father's debts and drawing a better salary.

According to D. M. Bose,[11] the research activities of J. C. Bose, extending from 1894 to 1937, the year he died, can be divided into three periods.

(1) During the first period, extending from 1894 to 1899, he produced the shortest of the then possible electro-magnetic waves (the microwaves), and extensively studied their quasi-optical properties. His researches with coherers not only led to the anticipation of semi-conductors but the effect of microwaves on the coherers led to the next important phase of his research.

(2) During the second period, extending from 1899 to 1904, began with his study of the fatigue effect in metallic coherers, used for detection of electric waves, from which he went over to the study of various other inorganic systems which exhibit stress under different kinds of physical stimulation. The similarities in responses of inorganic and organic systems led to his famous and controversial generalization about the responses in the living and the non-living.

(3) The third period that logically followed from the second phase led to his studies of Plant Electrophysiology and led to monumental investigations, which like most of his researches, were ahead of his time. These researches lasted till the end of his life.

1.9. Microwaves

To choose an area of research is always a difficult task. Jagadish had come across a book by Oliver Lodge on Hertzian waves and intuitively felt that this was an area that needed attention and he hit the bull's eye.

James Clerk Maxwell (1831–1879) had mathematically established that visible light is an electromagnetic phenomenon and constitutes a tiny section of the family of electromagnetic waves all of which travel at a constant speed of 300000 km/s. Heinrich Hertz (1857–1894) conducted a brilliant experiment in 1887 and startled the scientific world by generating electromagnetic waves having 66 cm wavelength (the distance from one peak of the wave to the next peak) which traveled through space and produced a spark at a distance. He carried out several experiments to show that these waves have similar properties as light. Unfortunately, he died young from something as treatable today as catarrh.[6]

The detailed history of the researches in electromagnetic waves will be recounted in the chapter that follows. Suffice it to say, Bose made a spectacular discovery, of producing radiation of wavelength of the order of 5 mm (called millimeter waves or microwaves). For comparison, this is 1/130 that of Hertz's waves. Incidentally, the wavelengths of visible light, of soft X-rays and hard gamma rays are of the order of 400–700 nm, 1/100 nm, and 1/10000 nm respectively (nm or nanometer is one billionth of a meter).

Microwaves, longer than infrared, can penetrate walls and Bose demonstrated in the famous experiment that he carried out in the Town Hall in Calcutta in the presence of Lieutenant Governor Sir William Mckenzie, how the electromagnetic waves traveled through space, penetrated three walls and activated relays that fired a cannon ball and rang a bell. Almost all descriptions

of this spectacular event emphasize how the waves penetrated the rotund body of the Governor.

That was in the year 1895. In less than a year after he stepped into the field of research, Jagadish, working alone, aided only by a tinsmith, produced an instrument that, for the first time, generated microwaves that would travel through space and activate relays.

Bose was fully aware that he was an experimental scientist and not a mathematical physicist as one of his much celebrated pupils S. N. Bose later turned out to be. His strength lay in planning and designing instruments to carry out experiments that would offer legitimacy to theoretical physics. The greatest experimental scientist ever, was Michael Faraday (1791–1867) who never had any opportunity to learn mathematics but to whom the world owes electricity and several other things. To Jagadish Bose, the world owes microwaves.

Bose undertook research on what may be termed as "Microwave Optics". He had realized right at start, that he should generate short waves that are closer to light waves in order to prove that the invisible electric waves or electromagnetic waves of Maxwell, have optical properties such as, reflection, refraction, polarization, etc. This would conclusively prove that all these invisible waves belong to the same family.

Bose published his first paper in the Asiatic Society and his second paper, "On the determination of the index of refraction of sulphur for the electric ray" communicated to the Royal Society of London for publication by Lord Rayleigh and another communicated in 1896 by Lord Rayleigh, in which Bose presented a unique method of measuring wavelengths of electromagnetic waves, led to the conferment of the DSc degree by the University of London with the rare distinction of his being exempted from further examination.[a]

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[a] It may not be widely known that J. C. Bose was possibly the first one to fabricate an X-ray unit in India. To quote Dr. D. M. Bose, the physicist and nephew of J. C. Bose from his speech delivered on 25th December 1948 in the Indian Radiological Congress, He (J. C. Bose) was the first in India to reproduce Roentgen's discovery in 1895, of the generation of X ray in a cathode ray tube. Reading a newspaper account, Bose then prepared Barium Platinocyanide screens with which he took X-ray photographs of different objects, like a human hand ... coins enclosed in a screen, etc. The equipment was later improved and Dr. Nilratan Sarkar used to bring his patients with bone fractures to Presidency College to get them X-rayed.[12]

1.10. Recognition from the British Administrators and the Press

That these early achievements of Bose were regarded highly even by the British Administrators in India is evident from the following letter of Sir Alfred Croft, initially an adversary of Bose, who held that, "Indians do not possess the requisite temperament for exact sciences". The following letter[13] was addressed to the Government of Bengal on 16th June 1896:

> *"The subject dealt with has long been regarded as of very great importance, attempting as it does to the complete specification of the unknown forces involved, by determining the length of the invisible wave ... The problem was attempted by Hertz, and subsequently by a number of continental physicists but the results obtained were very contradictory. Mr. Bose has recently succeeded in solving the problem with entirely satisfactory results; and a copy of the paper embodying his solution was sent to the University of London as a Thesis for the degree of Doctor of Science. I should explain that before being admitted to the examination for that degree, a candidate has to produce a Dissertation embodying the results of original research in some branch of Science. On the acceptance of the Dissertation by the University, the candidate has in general to undergo a further examination. There is, however, a provision in the D.Sc regulation that a candidate may at the discretion of the university be exempted from further examination, provided the paper submitted is of special excellence. Mr. Bose received on the 27th May, a telegram from the Registrar informing him that his Thesis was accepted and his presence at the examination excused.*

The Statesman of Calcutta had already carried a communication from Father Lafont the information about the Royal Society's acceptance of Bose's paper communicated by Lord Rayleigh and the desire expressed by the Royal Society to make a grant to Bose for the furtherance of original research (14th December 1895).

Bose had made several contributions by now and his important work on coherer action (the term coherer used for the detector of Hertzian waves was coined by Sir Oliver Lodge) is elucidated in Chapter 2. But it may be noted that *The Electrician* wrote a very perceptive lead article on Bose's wireless receiver.[13]

> *"His sensitive detector of electromagnetic radiation, perfectly prompt in its self-recovery, should serve to revolutionize the existing method of wireless telegraphy.*

> *The Calcutta Newspaper,* The Electrician *(18th January 1896) thinks that it would be a useful and remunerative work for some practically-minded men, "to devise a practicable system of electromagnetic light-houses, the receivers on board ship being some electrical equivalent to the human eye. The evolution of suitable generating apparatus would, we think, present difficulty; that of a suitable receiver, on the other hand, seems likely to give considerable trouble. In this connection, we would draw attention to the substantial and workmanlike form of Coherer devised by Professor Bose at the end of his paper, "On a new electro-polariscope". The sensibility and the range of this Coherer would appear to leave little to be desired, and it is certainly more likely to withstand the thousand and one shocks at sea than any of the forms hitherto brought about." ...*

Quoting the above from *Electrician*, the Englishman went on to say:

> *"Should Professor Bose succeed in perfecting and patenting his "Coherer", we may in time see the whole system of coast lighting throughout the navigable world revolutionized by the discoveries made by a Bengali Scientist working single-handedly in our Presidency College."*

That was the problem. Working alone, with very little funds to support his research and hardly any one around to discuss his results with, Bose was keen to visit England and present his results. Lord Rayleigh arranged an invitation from the Royal Society. Sir Alfred Croft strongly supported his application, concluding his note to the Governor, Sir William McKenzie.

> *"From the above, I hope, it will be clear that Prof. Bose is an investigator of exceptional originality and power and that he deserves all the encouragement that the Government can give him. In advocating his deputation to Europe on duty, I have in mind not merely his personal benefit, but also the resulting advantage to science."*

Sir William had the highest regard for Bose and his dispatch to the Home Department, on 30th June 1896 read,[13]

> *"The Lieutenant Governor strongly advocates the grant of the concession asked for. His Honour has done what he could to encourage and advance Mr. Bose's researches, as he thinks it is the duty of the great Government to do when it has a man of such exceptional qualifications as his staff, and he attaches much*

importance to Mr. Bose visiting Europe and conferring with the leaders of scientific enquiry there."

It clearly stands out from what is stated above that the British Government in India did not oppose Bose's advancement as is made out at times. It was partly the appreciation of Bose as a scientist and partly a deep sense of complacence the authorities felt that the benign administrative system of the Government promoted native talent and was anxious that it should be visible.

On 1st July 1896, the sanction of Bose's visit was officially announced:

"It has been settled that Prof. Bose should proceed at once on deputation to England to be present at a meeting of the British Association."

1.11. Instant Recognition by the British Scientific Elite and the British Press

Bose delivered a lecture to the British Association, Liverpool on 21st September 1896.

Described in his own words to a journalist after the lecture[14] was delivered in Liverpool, the lecture "dealt with an apparatus which I constructed for studying the properties of electric waves. Recent research has brought to light a new and vast region of forces. We knew of the properties of moderately rapid vibrations of ether which give rise to light. The slow and exceedingly quick vibrations of ether are invisible, and little is known about them. You see, our organs of perception fail us here, and there may be many wonderful forces working around us of which we know nothing. The slow ether vibrations known as electric waves, for example, have many remarkable properties, and the apparatus I exhibited before the British Association, was for the study of these properties".

As one of the pioneers who was unveiling the properties of the wave in the microwave region to an august audience comprising scientists like, Lord Kelvin, Sir Gabriel Stokes, Professors J. J. Thomson, Fitzgerald, Everett, Oliver Lodge, Sylvanus Thomson and a few continental scientists, young Bose (he was 38 years of age) was "a little nervous at the beginning. It has not often fallen on me to address such a critical audience. But I soon got interested in my subject and was encouraged by the kind manner in which the paper was received."[14]

After his paper, Lord Kelvin (1824–1907) (a renowned British Physicist who restated the second law of Thermodynamics and introduced the

Absolute scale of temperature which carries his name), not only broke into the warmest praise, but limped upstairs into the Ladies' gallery and shook Mrs. Abala Bose by both hands, with glowing congratulations on her husband's brilliant work. He did not stop there. Lord Kelvin wrote to Lord George Hamilton, then Secretary of State for India.

> *"It would be conducive to the credit of India and the scientific education in Calcutta, if a well-equipped physical Laboratory is added to the resources of University of Calcutta in connection with the Professorship held by Dr. Bose."*

This letter was followed by a memorandum drawing the Secretary of State's attention, reinforcing the need to set up a Physical Laboratory in Presidency College and this was signed by most of the scientists present at the lecture of the British Association and was also endorsed by Lord Lister, then the President of the Royal Society. The Secretary of state was strongly persuaded and so was Lord Elgin, the Viceroy of India.

But it took almost seventeen years through the cogwheels of various stages of Administration for this proposal to take shape and the foundation for the recommended Physical Laboratory was laid in 1914.[1]

Returning to Bose's lecture at Liverpool, the response was overwhelming. Bose gave several lectures after this and was invited to deliver a Friday lecture at the Royal Institution. This impressed the India office and Bose was given three months' extra leave allowing for his preparation and delivery of the lecture. The Royal Institution lecture delivered on 29th January 1897, was equally successful as his first lecture at Liverpool.

The London Spectator was effusive, describing Bose, a Bengalee of the purest descent, as a possible and "an invaluable addition to the army of those who are trying by acute observation and patient experiment to wring from Nature some of her most jealously guarded secrets. The people from the East have just the burning imagination which could extract a truth out of a mass of apparently disconnected facts ..."

The Times wrote:

> *"The originality of the achievement is enhanced by the fact that Dr. Bose had to do the work in addition to his incessant duties as Professor of Physical Science in Calcutta, and with apparatus and appliances which in this country would be deemed altogether inadequate. He had to construct himself his instruments as he went along. His work forms the outcome of his twofold lines of labor — construction and research."*

After Bose's Friday evening lecture at the Royal Institution, *The Electrical Engineer* expressed[13] "surprise that no secret was at anytime made as to its construction, so that it has been open to all the world to adopt it for practical and possibly money-making purposes".

This was one of the most perceptive comments made at that time which proved crucial to Bose's recognition as one of the inventors of radiotelegraphy.

The euphoria that followed Bose's lectures at Liverpool and at the Royal Institution was triggered off partly by the brilliance of the achievement and partly by the fact that the western press, prejudiced by the views of Macaulay and the likes of him, who believed that the eastern minds are incapable of rational thinking, was taken aback when Lord Kelvin, Lord Rayleigh, Lord Lister and many other scientists of great stature were really impressed by the achievements of an Indian, working out of a small laboratory, and having no funds or facilities, which leading scientists of the west were struggling to attain. No doubt that the lead came from Maxwell, followed by Hertz, Lodge, Popov and several others in Europe but the generation of microwaves was the key to Bose's success in proving the optical properties of electromagnetic waves, although all of them had established that these waves could travel through space without wires. Before he left England, Bose was invited to deliver a lecture on the electric ray at the Imperial Institute on 18th February 1897. Referring to his work, Sir Henry Roscoe, the Vice Chancellor of the University of London, acknowledged that "the Eastern mind was equally capable of making great scientific discoveries and producing experimentalists as eminent as those of the west.

J. C. Bose delivered lectures in Paris and at Berlin. At Berlin, Professor Warburg, the successor of Helmholtz told a research investigator anxious to take up researches in electric waves, "Bose has left you practically nothing to do: better try something else". Bose returned home to a hero's welcome when there was almost a stampede at the Howrah Station in Calcutta. Rabindranath Tagore went to Bose's house to meet him and having not found him there, left a bunch of Magnolia flowers for Bose and wrote a poem addressing Bose.[15]

"Across the oceans, on the western shore,
Reigns the temple of the Goddess
Of wealth of science.
There you have journeyed, my friend,
And returned richly crowned.
You anointed the motherland,
Modest at heart, poor and shy."

[Extracted (the first paragraph) from the translation from the original in Bengali by Sujata Basu Sengupta, July 1997, exactly 100 years after the original was composed by Tagore.[15]]

Bose returned home and rejoined Presidency College. He dedicated himself to his normal duties which left him with little time to pursue his research. He made an application to the Government of Bengal for some financial assistance for his research. The comments of the finance member in response (7th September 1897) to his application is worth quoting:

> *"He (Bose) is now drawing Rs 500 and it is simple nonsense on the part of a native gentleman in the service of the Government to talk, under such circumstances of "difficulty in maintaining himself on his small means". I wonder what any of the Universities in England would say to any of his staff who said, "I am a distinguished man, and you must agree to give me, on that account, more than the allowance of my offices". I think Mr. Bose has got his head a bit turned and can wait a bit for his distinctions and records."*

Fortunately, the Home member of the British Government (later Governor) supported Bose's request and wrote,

> *"Mr. Bose's distinction is not any ordinary distinction, and so as to the adequacy of his salary, I am personally aware that it has not been sufficient to meet the expenses of his experiments and tours."*

Bose was sanctioned Rs 2000 a year to support his experiments.

The second incident of Bose's brush with the authorities is interesting. Lord Rayleigh, the mentor of Jagadish and a distinguished member of the Royal Society, came to Calcutta and visited Jagadish's Laboratory at Presidency College. He spent a long time examining Bose's apparatus and the work he had been doing, further to what he had already seen in England and was very pleased with what he saw. The same evening, Bose received a note from the temporary Principal of Presidency College.[12]

> *"I learnt from Lord Rayleigh that he visited the Presidency College this morning and inspected the Laboratory over which he was shown by you. I should be glad to hear by what authority you have received outsiders into the Laboratory."*

These were the problems and pinpricks that Bose had to face almost constantly. But Bose would not give in and held his head high no matter how

some members of the Government would treat him. There were of course some who were very appreciative of Bose and his work. It was only to Tagore that he would, at moments of deep despair, pour out his heart.

1.12. Who Invented the Radio?

A question that is frequently asked in India is: "Who invented the radio? Or, should not J. C. Bose have received the Nobel Prize for inventing the Radio, at least jointly?" This has been discussed by Das Gupta[6] at length in the section, "a reluctant patent claimant" about J. C. Bose and will be dealt with in further detail in the chapter that follows. Das Gupta questions the commonly held belief that Bose anticipated Marconi by two years, and provides evidence to the contrary. Kochar[16] also shows that it was Bose's intransigence towards patenting that came in the way of his being recognized as one of the inventors of wireless telegraphy. The 1909 Nobel Prize for Physics was awarded to Guglielmo Marconi (1874–1937) and C. F. Braun (1850–1918) for wireless telegraphy.

1.13. Guglielmo Marconi

Marconi was not really a physicist. At a very early age, when he was not even 20, he was fascinated by the experiments of Hertz and wanted to send Morse signals without wires using Hertzian waves. He might have been exposed to the work of Oliver Lodge as Bose was. There is evidence that Marconi produced electromagnetic waves and demonstrated their effects to his parents in 1895. He went to England and demonstrated his wireless wave transmission to the Chief Engineer of British Post Office Mr. William Preece and demonstrated it on the Salisbury plain. Marconi filed for Patent and got it in 1897.

Marconi made history when he transmitted the Morse code of "S" across the Atlantic, from Cornwall in England to Newfoundland in Canada on 12th December 1901. (Thomas Alva Edison, the greatest inventor of all times, was not impressed and openly said that the reception of a signal across the curved surface was impossible since these waves cannot bend as light does not bend and the whole thing was a "figment of Marconi's imagination". Edison was proven wrong after the discovery of the ionosphere which reflects electromagnetic waves of long wavelengths.) Marconi did not stop at this. He traveled in a ship SS Philadelphia in February 1902 from England to America and kept receiving radio signals that were transmitted by his assistants every day and got the Captain of the ship to endorse the signal reception.

The transatlantic signal transmission was hailed all over the world and Guglielmo Marconi spared no pains to establish that he was the pioneer in wireless telegraphy. A big dinner meeting was arranged in his honor in America, attended by Graham Bell, the inventor of telephones. Marconi in his speech in the meeting is said not to have mentioned Bose or even his childhood friend L. Solari in the Italian Navy who it is believed, marginally modified Bose's technology of the coherer, to help Marconi receive the transatlantic signals.[15]

Marconi had a single point agenda. He wanted to perfect wireless telegraphy. He was a good engineer and a shrewd businessman and had limited knowledge of Physics. He seemed not to have much compunction about using whatever technology he could get hold of. (Nikola Tesla, whose contributions to radio-wave propagation are hardly ever mentioned, said that Marconi had infringed 17 of his patents in arranging his radio wave transmission.) According to the Proceedings of the US Naval Institute, the "coherer" was the only novel element in Marconi's wireless system but he does not indicate who its originator was. It is likely to be the Branley coherer,[15] modified by Bose.

Marconi was highly connected with the Italian aristocracy and the British Royalty. His sending a message from Theodore Roosevelt, President of USA. to King Edward VII, in 1901, not only indicates his connections at high level, but his sharp sense of what made news.

1.14. Bose's Aversion to Patenting

Bose has been blamed[16] for his intransigence with regard to patenting. If he had taken out a patent, there would, no doubt, be a much greater acknowledgment of his contribution to wireless telegraphy. Several authors have done considerable hair-splitting in trying to establish precedence of one over the other. Das Gupta has clearly established that Nivedita's claim in her letter to Tagore[17] that Bose preceded Marconi by two years, is not substantiated. Her statement may have given rise to the widely-held belief in India that Marconi cheated on Bose. If, one were to go by months and the year, in achieving remote signaling, Bose may have been slightly ahead of Marconi.

As was apprehended by the *Electrical Engineer*, there was no bar to making use of the technology which Bose had spelt out without going for a patent and legally it was perfectly acceptable if someone took advantage of Bose's invention.

What Marconi did to commercialize the radio, Jagadish Chandra Bose did just the opposite. The following section from Das Gupta[6] is a transcription of Bose's letter to Tagore:

> *"A week after his lecture in the Royal Institution in May 1901, Bose wrote to Tagore that just prior to the lecture, the proprietor of a famous telegraphy company (most likely Alexander Muirhead, a D.Se in 'Electricity') had sent him a cable indicating that he wanted to see Bose urgently. When they met, he pleaded with Bose not to reveal the details of his work in the lecture but, rather, allow him to take out a patent on Bose's behalf, so that they may share in the profit."*

Bose's repugnance at the overture made by the billionaire, "who to make further profit, came to me like a beggar", was undisguised. "If only Tagore would witness the country's (England's) greed for money", he wrote in disgust. "What a dreadful all-consuming disease it was".

The objectives of Bose and Marconi were obviously entirely different. Bose was not particularly interested in the engineering of wireless transmission. Being a physicist, his objective was to study Microwave Optics and its properties, with the ultimate objective to verify Maxwell's electromagnetic wave equations. Since he used millimeter waves which are closer to light waves, he could, with relatively small apparatus, prisms, polarisers etc. get consistent results which earned him wide acclaim from the best-known scientists in Europe and he found himself almost in the centre stage of Physics and nothing pleased him more.

1.15. Nikola Tesla

In fact one name is seldom mentioned in this country or in Europe with regard to his contributions to distance signaling or wireless telegraphy. The person concerned is one of the greatest engineering geniuses of the 19th and 20th century. He was a Serbian American called Nikola Tesla. (Apart from the world-wide use of alternating currents that we owe to Tesla, there are other things in daily use like induction motors that we use for fans, electric motors etc.) Going by American patents, he precedes Marconi. Marconi used Tesla coils and earthing for his transmitters and when Marconi sued Tesla, for patent infringement, Marconi lost and Tesla was recognized by the American Court to be the inventor of Radio telegraphy.

As has been stated earlier, radio telegraphy was the single point agenda in Marconi's life and he moved heaven and earth to make it widely acceptable.

His management talents and his aristocratic connections helped and so did the First World War.

Tesla was engaged in his new inventions as was Bose. After his early success with signal transmission, Tesla tried to transmit electricity without wire. But being a poor manager, both of engineering and finance, he died in poverty.

Bose's treatment of Dr. Muirhead in not only rejecting his proposal which was quite fair, was perhaps somewhat harsh and his letter to Tagore was a bit of an overreaction that stemmed possibly from his spirit of nationalism or a firm belief that knowledge must not be commercialized, or both. Geddes described him as an Indian rishi *(hermit)* free from greed.[1]

But sacrificing self interests for noble causes is not unknown in the materialistic culture of the West. Nikola Tesla, for example, tore up his contract papers with Westinghouse, when the latter told Tesla that his dream AC system may never see the light of the day if the royalties promised to him were to be met. "Is Science going to suffer?" was the only question Tesla asked. When Westinghouse answered in the affirmative, Tesla threw the torn contract papers into the fire.[18]

Had he not done so, it has been estimated that Tesla would have made several billions of dollars. He had to declare himself bankrupt in 1916 and died in abject poverty as mentioned earlier. To summarize, neither Bose nor Tesla made any attempt to make their inventions commercially viable systems for wireless telegraphy. Marconi did everything possible to achieve commercial success and he did it. It is in India that J. C. Bose is credited as the inventor of radio and Tesla in America. No wonder and understandably so, Marconi is credited as the inventor of Radio in the rest of the world, since "History is written by the winners".

But before we conclude this much debated topic, it is worthwhile to refer to Bandyopadyay,[15] who in his well-researched paper, shows, quoting Braun's Nobel lecture, that apart from his finding out that Galena (lead sulphide) conducts more electricity in one direction compared to the other (in 1874), Braun did precious little towards its application as a microwave receiver during 17 years until Bose established this, as acknowledged by Pearson and Brattain.[19]

> *'The demonstration of the existence of radio waves by H. Hertz in 1888 created potential demand for a suitable detector, but it was not realized until*

1904 (Bose's American patent), that semiconductor rectifiers were well-suited for this purpose. J. C. Bose found that point contacts (cat whiskers) on galena, silicon carbide, tellurium, silicon etc. were good detectors of radio waves."

This is discussed in detail in the next chapter but one may see that Bose can be rightfully credited for having been one of the pioneers of solid state physics. This would have gone unnoticed had it not been for the US Patent granted to Bose in 1904, based on the application made on his behalf (in 1901), by two women from the West: one Mrs Sara Bull, an American and the other Sister Nivedita, an Irish woman. It is interesting to note that two western women literally forced Bose to write the patent application in the required format. Mrs. Bull paid the required fees (which Bose subsequently returned to Mrs. Bull and Mrs. Bull on her turn gave the cheque back to Mrs. Abala Bose, possibly for her school). It is on record[15] that Sir Neville Mott, Nobel Laureate in 1977, for his contributions to solid state electronics remarked,

"J. C. Bose was at least 60 years ahead of his time and he had anticipated the p-type and n-type semiconductors."

Bose had shifted his interests from microwaves to finding the line of demarcation between the living and non-living and switching from there to Plant electrophysiology.

Bose's scientific interests were so compelling that he had neither the desire nor the time for commercializing his ideas and products. More importantly, he possibly lacked the talent for commerce. Albert Einstein was supposed to have started a company for making refrigerators and it flopped.

When Marconi was fighting one law suit from another, trying to establish the claims of his companies, Bose was immersed in a different world of scientific discoveries. Besides, he never made any official claim to being the pioneer of radio telegraphy and his nephew Prof. D. M. Bose recalls that when he (J. C. Bose) was to be asked as to who was the inventor of the radio, his answer used to be, "The invention is more important than the inventor."[11] He was so consistent about his faith of distributing the fruits of one's labour without thinking of personal benefits that he made it one of the rules of the constitution of the Bose Institute that he set up, that "no invention from this Institution should be patented".

1.16. Responses of the Living and the Non-Living

It was 1899. Bose was by now well-established as a physicist of world repute. He had already published a large number of papers in reputed scientific journals, most of these in the *Proceedings of the Royal Society*. The attitude of the British administrators in Calcutta towards the scientific abilities of Indians had somewhat changed, certainly with regard to J. C. Bose. But his teaching schedule was still very hard by all standards, in addition to all the examinations that he had to grade. It is amazing to think how Bose continued his front line research. With the tinsmith that he had trained, he kept producing unbelievably accurate instruments during those pre-electronic era and carried out his experiments.

Bose was still engaged in his researches for developing suitable receiving instruments for his microwaves when he noticed something rather strange! The metallic coherer for receiving radio waves if used continuously became less sensitive, but returned to normal after a period of rest, much like us or living beings. Being a thorough-bred experimenter, he carried out his tests with various materials and stresses. To his amazement, the curves produced by slightly warmed magnetic oxides of iron showed striking resemblance to those of muscles. In both, response and recovery diminished with exertion and the consequent fatigue removed easily with "massage".

Where is then a boundary line between the living and the non-living? Is there a boundary? The enormous amount of work that he carried out in this context was reported in a long paper and two years later in the volume that was published with the title, "The response of the living and the non-living". One can see how the physicist was drifting towards physiology. To quote Geddes,[1]

> *"It yielded such abundant and surprising results that Bose, for whom there was still no scientific public in India, nor even a single colleague with whom he could discuss his problems, was feeling the need of a new journey to Europe."*

It was a happy coincidence of timing that the International Congress of Physics to be held at Paris in 1900, cordially invited him to present his paper. The Lieutenant Governor of Bengal who had very high regards for Bose decided to depute him and he observed that the "the visit of Professor Bose

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to Paris will be of great advantage to the singularly original researches in which he is engaged."

Bose reached Paris in the month of August 1900 as a delegate from the Governments of Bengal and of India. It was for the first time that parallelism was being drawn between the living and the non-living. The paper was regarded as one of the most important received by the Congress and it was published in its volume. The audience in the conference was awestruck.

Among them was Swami Vivekananda, who was overwhelmed. Swami Vivekanada (1863–1902) was an Indian Spiritual leader, and a reformer. A disciple of the mystic Sri Ramakrishna, he traveled widely and was responsible for introducing the Vedantic Philosophy to US and Europe.

In one of his letters he wrote:

> *"Here in Paris have assembled the great of every land, each to proclaim the glory of his country.... Among these peerless men gathered from all parts of the world, where is thy representative, O thou the country of my birth? Out of this vast assembly, a young man stood for thee, one of thy heroic sons, whose words have electrified the audience, and will thrill all his countrymen."*

Tagore, the lifelong friend of Bose wrote:

> *Whence hast thou that peace*
> *In which thou in an instant stoodst*
> *Alone at the deep centre of all things;*
> *Where dwells the One alone in Sun, Moon and flowers,*
> *In leaves and beasts and birds and dust and stones,*
> *Where still one sleepless Life on its own lap*
> *Rocks all things with a wordless melody,*
> *All things that move or seem motionless.*
> *Call thou thy scholar-band come forth*
> *Out on the face of nature, this broad earth.*
> *Let them all gather. So may our India,*
> *O once again return to steadfast work,*
> *To duty and devotion, to her trance*
> *Of earliest meditation.*

[Translator unknown. From Ref. 1.]

Two things are apparent from what Vivekananda and Tagore had to say in praise of Jagadish Chandra:

(i) How intensely they, including Jagadish Chandra, felt for their country.
(ii) How Vedic philosophy strongly influenced their thoughts.

In Tagore's poem, quoted earlier, we notice the same pining for the motherland. It was this spirit which was largely responsible in driving these brilliant minds to the pinnacle of their achievements. (Tagore had not yet received the Nobel prize (1913) but he had already made an indelible mark on Bengal through his poems, writings and his songs.) Bose wrote to Tagore, how he was feeling uneasy before a lecture of 10th May 1901 at the Royal Society, when he envisioned a woman (was it mother India?) in rags who muttered, "I have come to greet you" and all his uneasiness instantly disappeared.[12]

British rule in India had crossed 150 years. It seemed firmly entrenched. The large majority of people, mostly in villages, lived a miserable existence. Famines were common and took heavy tolls. The intelligentsia, some of them of outstanding merit and academic distinction, were blatantly discriminated against. This may explain why the search for self-esteem and national parity attained salience among the Indian elite at that time and prompted Bose to say:

> *"Now the time has arrived, we must spend our entire energy in glorifying our motherland."*

And so he did.

There were others who were not motivated by patriotic feelings as the Indians were, in celebrating Bose's startling findings, but by their philosophical implications. Romain Rolland, Aldous Huxley and George Bernard Shaw were the leading intellectuals of Europe among them.

1.17. Bose's Philosophical Orientation: Did It Influence His Science?

Bose has been described[7] rightly as:

> *"A cosmopolitan in the best and widest sense of the term yet a nationalist in the noblest sense, Sir Jagadish Chandra's fundamental attitude to life, his cultural*

> *sympathy and outlook were primarily Indian. With the best of world culture incorporated in his personality, he was held in the esteem and love of not only his compatriots, but also the highest regard of the leading thinkers in every field of knowledge all over the world."*

He owes much of his strong nationalism to the early education he had with the boys of his village in the Pathshala, referred to earlier and to his father.

As we have said earlier, Bose's father had adopted Brahmoism which was founded by Raja Rammohan Ray primarily for cultural and social reform in India as his personal letter to Dr. Tuckerman would show.[7]

> *"I regret to say that the present system of religion adhered to by the Hindus is not well-calculated to promote their political interest. The distinction of castes introducing innumerable divisions and sub-divisions among them has entirely deprived them of patriotic feeling, and the multitude of religious rites and ceremonies and the laws of purification have totally disqualified them from undertaking any difficult enterprise... It is, I think necessary that some change should take place in their religion, at least for the sake of their political advantage and social comfort."*

And that is how the "Brahmodharma", based largely on the Upanishadic monism, came about, influenced to some extent by Christianity and Islam. It may not be irrelevant to state in this context that it was the same Rammohan Ray who was instrumental in the abolition of *Sati*.

Dwarakanath Tagore, grandfather of Rabindranath the poet, did not adopt Brahmoism but as a great reformer, he lent considerable support to this movement. Rabindranath's father contributed significantly to this movement and Rabindranath was greatly influenced by Brahmoism. Vivekanada, however, started as a great Hindu reformer, his philosophy also based on the Upanishads. Ever anxious to rid Hinduism (as above, described by Rammohan Ray) of its stagnation, he devoted his rather short life (he died at the age of 39) to the service of people and his preachings reached beyond the boundaries of Bengal and still survives all over the country. Brahmoism, confined mostly to the Bengali elite was committed to the more abstract monism of the Upanishads, and possibly had more cerebral appeal than emotional and "slowly drowned in the blue blood of its elitist carriers".[2]

Bose's Royal Institution discourse (10th May 1901), summarizes his observations:

> *"I have shown you this evening an autographic record of the history of stress and strain in the living and the non-living. How similar are the writings? So similar indeed that you cannot tell one apart from the other. We have seen the responsive pulse wax and wane in the one as in the other. We have seen response sinking under fatigue, becoming exalted under stimulants and being killed by poison.*
>
> *Amongst such phenomenon, how can we draw a line of demarcation, and say here the physical ends, and there the physiological begins? Such absolute barriers do not exist.*
>
> *Do not these records tell us of some property of matter common and persistent? Do they not show us that the responsive processes, seen in life, have been fore-shadowed in non-life — that the physiological is related to the physico-chemical — that there is no abrupt break, but a uniform and continuous march of law?*
>
> *If it be so, we shall but turn with renewed courage to the investigations of mysteries, which have too long eluded us. For every step of science has been made by the inclusion of what seemed contradictory or capricious in a new and harmonious simplicity. Her advances have been always towards a clearer perception of underlining unity in apparent diversity.*
>
> *It was when I came upon the mute witness of these self-made records, and perceived in them one phase of a pervading unity that bears within it all things — the mote that quivers in ripples of light, the teeming life upon our earth, and the radiant Sun that shines above us — it was then that I understood for the first time a little of that message proclaimed by my ancestors on the banks of the Ganges thirty centuries ago — "They also see but one, in all the changing manifoldness of the universe, unto them belongs Eternal Truth — unto none else, unto none else!"*

It was his faith in universalism which may have made Bose mentally bridge the gap between the living and the non-living, the boundary line between the two is still somewhat undefined.

The endless philosophical arguments and disputes among the reductionists and the vitalists in Europe over centuries, and those who were in between, continually influenced the personalities and even scientific judgements of scientists in Europe. A typical example is Hans Christian Oersted (1777–1851) the Danish scientist, who during a classroom

experiment serendipitously discovered the link between electricity and magnetism (1819).

It is believed that the profound influence of the philosophies of Immanuel Kant (1724–1804) and that of Friedrich Schelling (1775–1854) lent meaning to his experimental observation. He could see a pattern that matched with his philosophy and this led to the discovering of electromagnetism.

Oersted proved to be right. But Bose, influenced by the Waller dictum[6] that in living tissues, the most delicate and universal sign of livingness is the electric response to stimulation, and with his nationalistic fervor and faith in universalism, may have rushed to conclude what he did, only from the similarities of electric response. Bose and many illustrious thinkers of his time who were somewhat carried away when Bose's experimental results appeared to hold an answer to the unresolved philosophical question and their faith. Bose possibly made the mistake of basing his conclusions on the fulfillment of necessary conditions of electric response only and did not look for sufficient conditions.

To quote D. M. Bose,[11]

> *"Bose was not familiar with the contemporary physicochemical investigations carried out by men like Ostwald, Bredig and their school, and was therefore unable to undertake a correct interpretation of these borderline investigations of his. While his Western contemporaries designated them as inorganic models of some properties of living system, Bose with his pantheistic background saw in this similarity an evidence that 'the responsive process seen in life has been foreshadowed in the living'."*

Bose's presentation in the Royal Society evoked mixed response. Some were ecstatic and some skeptical, and Das Gupta believes, this was when Bose began to be marginalized as a scientist in the western world.[6]

Two letters from Bose to Tagore[12] quoted in parts (the sections in Bengali translated by the author), provide a glimpse of this marginalization, the agony and ecstasy suffered by Bose, ostracized by some and praised by others and struggling to hold his own.

1.18. Plant Electrophysiology

There is a standard misconception, generally amongst Indians, that J. C. Bose had shown that plants have life. That plants have life has been known for millennia.

Bose carried out a number of very sensitive experiments and showed how all plants respond to various stimuli. Poetically he wrote, "These trees have a life like ours. They eat and grow, face poverty, sorrows and suffering. This poverty may induce them to steal and rob, they also help each other develop friendships, sacrifice their lives for their children."

Studying plants was the obvious step to be taken in Bose's exploration of the boundary, if any, between the living and the non-living. The physicist Bose had already drifted towards physiology and now he was moving towards plant electrophysiology. Contrary to popular belief, Bose did not leave physics. Bose was an extraordinary experimenter and he used all his knowledge in physics to design instruments which helped him to measure minute responses or movements in plants which, in the pre-electronic era, were inconceivable. Bose stayed back in London after the Paris Conference for two years, and a part of this leave was without pay. Jagadish received generous grants to partially meet his expenses provided by Maharaja Radhakishore Devamanikya of Tripura, at the entreaties of Rabindranath Tagore.[17]

Bose had been offered the facility of working in the Davy–Faraday Research Laboratory for two terms. His second friday evening discourse in the Royal Institution, London, was on "The response of inorganic matter to mechanical and electrical stimulus".

Bose's drifting into the realms of Physiology met with a lot of opposition. Bose suffered considerable mental agony during his stay away from home, family and friends with formidable opponents decrying his work in electrophysiology. Brief extracts from his letter of 21st March 1902 to his friend Tagore[12] would help to bring out what he was facing and how he felt.

Dear Friend,

...your letter momentarily brought me home to your peaceful ashram from the battle ground where I am placed now.... You will have heard of Sir Burden Sanderson. Sanderson and Waller occupy the highest thrones in the kingdom of physiology. ... When I commented during my lecture at the Royal Society that plants which come between the living and the non-living will provide similar response, Burden Sanderson told me that he had worked all his life with plants. Only mimosa (touch-me-not) responds to touch. That ordinary plants should give electrical response is simply impossible. It cannot be. He further added, "Professor Bose has applied physiological terms in describing his physical effects on metals. Although his paper has been printed, we hope

he will revise it and not use our physiological expressions in describing phenomena of dead matter."

I told him in response that scientific terms do not belong to a particular discipline and if some phenomena are similar, it is pointless to introduce different terminology. Needless to add, my paper has not been published and has been archived following 'a conspiracy of silence'.

... Meanwhile, I accidentally met Professor Vines, the renowned authority among vegetable physiologists and President of the Linnean Society who came to see my experiments with Professor Hornes (successor of Julian Huxley at the Royal College of Science) and I can hardly describe how they were delighted to see my experiments. Professor Hornes repeatedly kept saying, "I wish Huxley had been living now; he would have found the dream of his life fulfilled."

After this, Professor Vines, as the President of the Linnean Society, invited me to speak. In the galaxy of physiologists and biologists, your friend was all alone in a battleground, ready to take on the challenge. Just 15 minutes had elapsed, and I realized I was winning the battle! Heard many words of praise, Bravo Bravo!! being shouted. I arrayed the whole range of phenomena of animal and plant response. The President came on the dais three times to ask if anyone had any questions. There were none. Only Professor Harlog stood up to say, "We have nothing but admiration for this wonderful piece of work."

So, after months of struggle, I have achieved success. There is a lot more to be done. I do not really know how to go about it now. I feel totally drained out and I am hankering for rest and solitude. But I have to feed fuel to the fire that I have lighted. Please tell Maharaja about all this. Had it not been for your efforts, I would have to return home with nothing but failed efforts.

I send you my heart-felt love.

Jagadish

The response of Tagore was full of comfort and rejoicing at Bose's ultimate success. It verged on ecstasy.

The President of Linnean Society wrote to Bose:

"It seems to me that your experiments make it clear beyond doubt that all parts of plants — not merely those which are known to be motile — are irritable, and manifest their irritability by an electrical response to stimulation. This is an important step in advance, and will, I hope, be the starting point for further researches to elucidate what is the nature of the molecular condition which constitutes irritability, and the nature of the molecular change induced by a

stimulus. This would doubtless lead to some important generalization as to the properties of matter, not only living matter, but non-living matter as well."

Bose was not prepared for what was happening behind the scene, happy as he was with the encouragement that he kept receiving from his mentor Professor Vines and others from the Linnean Society. When he came to know of the conspiracy, as he called it, he went into a deep depression and his mail to Tagore dated 8th May 1902, brings it out.

Dear Friend,

... What would I not give to have you here with me now! I cannot express in words what I have been going through at the moment. I never wrote to you earlier about all the impediments that I am having to face lest you should all feel unhappy. The paper that I wrote for the Royal Society in May last year has not been published, thanks to Waller and B. Sanderson. Waller published my results as his own in a journal last November. I knew nothing about this but when my paper to the Linnean Society was being considered for publication, friends of Waller raised objections, stating that these results have already been published by Waller. The proceedings of the Society meetings being confidential, no one told me anything about what was going on. After investigations, Linnean Society has decided in my favor and have decided to publish my paper.

The President has written to me, "There are many queer things you have yet to learn. But I am glad that you now have fair play ..." I heard many things from him. It is pointless to discuss them here in a letter. Don't tell anyone about all this. If your faith is shattered, what do you live with? I would have broken through these barricades of conspiracy if I could stay here long enough. But I feel totally dejected. I want to come home and touch the soil of India and feel rejuvenated. If I can come back here later, I may do. But I don't want to think of the future now.

Yours,
Jagadish

Das Gupta[6] has discussed the Bose–Waller conflict in considerable detail. Providing evidence that Bose was "niggardly in admitting his debts to other scientists", Das Gupta points out that Bose never acknowledged his visits to Waller's laboratory (except in a letter to Tagore[12]) where, according to Waller, he (Bose) had picked up some techniques which he used in his paper

presented to the Royal Institute in May 1901. On the other hand, Waller, claiming precedence of his paper of November 1901, which has very close resemblance to the one of Bose (May 1901), which was archived but available to Waller, stating that an archived paper (referring to Bose's paper) cannot be considered to be a 'valid document' on which priority can be claimed, Das Gupta concludes:

> *"As for Waller, his argument concerning Bose's archived paper with its brief but final section was disingenuous to say the least. If Bose was guilty of failing to record his debt to Waller, so too must be the latter be found severely wanting in grace for not mentioning Bose, even in a footnote, in his paper in the Journal of Physiology. Both men were severely lacking in scientific civility."*[6]

Bose may be blamed for not owning up the benefits that he may have derived from his visits to Waller's laboratory (except in his letter to Tagore), but can this omission be placed in the same category as plagiarism?

The details of Bose's studies in Plant electrophysiology and their relevance, if any, in the light of modern developments of the subject are discussed in Chapter 3 of this monograph.

1.19. Bose and Tagore

Jagadish Chandra and Rabindranath Tagore were as different from each other as two men could be. Bose was short, stout and handsome. Tagore was tall and a very good-looking man. Jagadish came from East Bengal and had an accent, Tagore from a very aristocratic family of old Calcutta and very suave. Jagadish in his early years loved big game hunting which he gave up later. Tagore would abhor any such thing. Jagadish was three years older than Tagore and they did not meet each other till they were about forty years of age. Jagadish had made a name for himself with his dramatic success in generating microwaves and sending a signal to a distance in his famous Town Hall experiment and all the adulations that he received after his lecture demonstration in England.

Bose was very pleased that Tagore had called after his return from England and it was from then that their friendship grew and it grew very rapidly. Apart from the fact that both Tagore and Bose shared the same religious philosophy, they complemented each other, the poet and the scientist. Tagore, the poet, had no training in science but had a deep interest in it;

Fig. 9. Rabindranath Tagore.

Bose, the scientist had a flare for literature. What is more, as has been mentioned earlier, both Tagore and Bose had strong patriotic feelings like the renaissance men of the time and that acted as a bond between the two. In the poet's own words:

> *"I found in him (Bose), a dreamer, and it seemed to me, what surely was a half truth, that it was more his magical instinct than the probing of his reason which startled out secrets of nature before sudden flashes of his imagination. In this I found our mutual affinity but at the same time our difference, for to my mind he appeared to be poet of the world of facts that waited to be proved by the scientist for their final triumph, whereas my own world of visions had their value, not in their absolute probability but in their significance of delightfulness."*[12]

Jagadish shared many moments of this delightfulness with Tagore, sitting with him in Tagore's House boat on the river Padma, listening to his delightful songs, or his poems or his short stories. Jagadish always made it a point to read one of Tagore's poems before going to bed. Jagadish, in his turn would tell Tagore about science and discoveries and

it is believed that Jagadish prevailed on Tagore to write his famous poem on, Karna and Kunti. As the letters quoted above would show, Jagadish made it a point to write to Tagore at length and Tagore would promptly send his reply providing the emotional succour that Jagadish needed so badly. Tagore did his best to help Jagadish get over his depression. He did his utmost to collect money to support a good part of Jagadish's stay in England and Jagadish was very grateful as his letter (21st March 1902) indicates.

Tagore lost his wife when he was barely 42 years old, a few years after he met Bose. He lost his son in 1908 and eldest daughter in 1918. When Tagore's second daughter fell ill and had breathing difficulties, Jagadish had an equipment fabricated to turn oxygen into ozone (by electric sparks) to help her breathing (letter on 17th March 1903).

Jagadish and Abala suffered with Tagore's bereavements, although Tagore, stoic as he was, always kept his grief to himself. Tagore had very high regards for Abala Bose who reciprocated his feelings. Abala, deprived of a child as she was, had a motherliness that attracted others towards her.

Two other letters from Jagadish to Tagore may be worth quoting. The letters were crisp and written in Bengali[12] as their later letters usually were. The first one was on Tagore's receiving the Nobel Prize.

Dear Friend, *19th November 1913*

All these years, I felt a deep anguish that you had not been bedecked with the world's greatest honour. Today, I do not feel so any more. How may I express my gratitude to Almighty God? Go from strength to strength. Let victory be always yours. Let "Dharma" be your eternal companion.

Yours,
Jagadish

The second one was written when it came to be known that Tagore had renounced his knighthood in protest against British atrocities in Jallianwalabag (1919) in Punjab. (Several hundred Indians, including many women and children were fired upon and killed. They had assembled in a peaceful meeting and all exits were blocked by the soldiers before the firing started. General Dyer who ordered the killing was unrepentant and was reprieved after a mockery of trial.)

Bose wrote just a line to Tagore in appreciation:

Dear Friend, *2nd June 1919*

You have divine blessings on you …

Yours,
Jagadish

Nandy,[2] as well as some others,[20] concluded that their friendship waned towards the end. It is true that the letters exchanged between the two were much fewer than before. There may have been some misunderstandings but the warmth of their love remained till the end. Both of them were getting busier, having set up two Institutions and finding it hard to sustain them.

Jagadish dedicated his famous book *Nervous Mechanism in Plants*

"TO MY LIFE LONG FRIEND RABINDRANATH TAGORE"

Tagore's reply to Bose's letter (21st April 1926) on his return from the US was:

> *"When I received your book, I realized, 'here lies our Truth, the Light and Life, the eternal manifestation of India. The fatigue that had come over me dissolved by the warmth of friendship that was conveyed by your letter."*

Jagadish's letter to Tagore (11th July 1932) expressing his delight after Tagore's visit to Iran and also his grief on the death of Tagore's grandson (the son of Meera, Tagore's daughter), and the one in 1936, sending some money to help Tagore's ViswaBharati University were sincere expressions of his feelings. It needs to be noted that both of them were approaching seventy years and their professional and social commitments were multiplying, and Tagore's health in particular was deteriorating.

Tagore's memorial address on Bose, after his death (partly, quoted at the end) bears testimony to the love and respect they had for each other.

1.20. Bose and Nivedita

Bose and Sister Nivedita met around 1898. It was friendship at first sight. Jagadish was about 40 and Nivedita 31. Nivedita or Margaret Noble

(1867–1911) was from Ireland. She was fascinated by Vedantic philosophy preached by Vivekananda and became his disciple. Her first visit to India was in the year of 1898 when she came to get acquainted with the people in India. Jagadish had just returned after his triumphant visit to England. Nivedita came to visit him at his Laboratory at Presidency College, Calcutta, with Mrs. Sarah Bull (or Ole Bull), an American and wife of a musician. They were both upset to see the sad condition in which Bose had to carry out his research. Nivedita went back to Ireland to return permanently to India. Nivedita was most impressed by the stamina and determination of Bose against the adversities that he had to face.

Nivedita became a close friend of the Bose couple and she joined hands with Abala Bose in her efforts to promote women's education. Nivedita worked relentlessly, serving people in distress. When plague broke out in Calcutta, she was there in the forefront, cleaning up streets, trying to contain the epidemic.

Nivedita came to know Tagore, possibly through Bose and became good friends. In her long account of her assessment of Bose's scientific work,[17] she was reasonably accurate, appreciative of Bose's talent and abilities to exert himself against all odds:

> *"He began to publish Papers through the Royal Society in, I think, the year 1894. From that date, working under all his difficulties as he was, he published 2 or 3 every year till he left for Paris in 1900. (One paper in 2 years is considered good record for a life surrounded by advantages.) Professor Bose's work was in each case completely original and in a special sense accurate and exhaustive. He was like a man haunted by the fear that if he failed at any point, his people would be held to have no right to education. 'Everyone knows that we have brilliant imagination', he told me, when he was fighting against death*[b] *in London in 1900, and still struggling to make a record of his latest discoveries, but I have to prove that we have accuracy and dogged perseverance besides, and he did prove it."*

Nivedita assisted Bose for hours on end and edited thousands of pages of his manuscript for the books that were published by Longman and asked for nothing in return.

After the early death of her Guru, Swami Vivekananda (1902), Nivedita had more time for Bose. It has been mentioned earlier in the chapter that

[b] Jagadish had been afflicted by some problem and apparently collapsed after an exhaustive lecture. He was operated upon and he fully recovered.

Fig. 10. Sister Nivedita.

Nivedita and Mrs. Bull virtually forced Jagadish to apply for an American Patent on his work on the Artificial eye.[15] Bose used to address Mrs. Bull as "Ma" (Bengali for Mother) and could not refuse her request. Bandyopadhya[15] writes that it was Swami Vivekananda who prevailed on Bose to apply for a patent and it was on his insistence that Nivedita and Bull organized the application.

Nivedita joined the Bose family in many travels that they undertook. She died in Darjeeling in 1911, at only forty-four years of age. She had left an indelible mark on Bengal and is still affectionately referred to as Sister Nivedita.

1.21. Bose's Contributions to the Growth of Western Science in India

It was not Bose alone who ushered in Western science into India as many Indians tend to believe. That is not quite true. As has been described earlier in the chapter, despite the initial indifference of the British authorities, western education began to trickle in. Raja Rammohun Ray helped the flow. Christian missionaries, particularly from the continent, made significant

contributions. Dr. Mahendralal Sircar, and later Sir Asutosh Mukherji set up Institutions. Acharya P. C. Ray set up an Industry, and also made significant academic contributions. Jagadish Bose gave this movement a hefty push and with his contributions to original research, established to the world that Indians were perfectly capable of carrying out studies which the West recognized as rational. He came to occupy the centre stage in the study of electromagnetic radiation. He was marginalized in his researches in Plant electrophysiology, partly because of professional jealousy, partly because he got carried away with his own theories, often indifferent to what was happening elsewhere in the world and also because in several cases he was many years ahead of his time.

Bose re-introduced experimental research in India. In this context, it would be pertinent to quote from the Foreword to the book by Jagadish Chandra, containing a collection of his papers by Sir J. J. Thompson who discovered the particle electron in 1897 and received the Nobel Prize in Physics in 1906.[15]

> *"... The papers make very agreeable reading, for the author is never dull. Another aspect of these papers is that they mark the dawn of the revival in India, of interest in researches in Physical Science. This which has been so marked a feature of the last thirty years, is very largely due to the work and influence of Sir Jagadish Bose."*

Bose continued to teach Physics at Presidency College on his return from England until his retirement in 1916. He was offered Professorship at Oxford many years earlier and declined it to serve Presidency College and more importantly, the cause of science in India.

Bose dreamt of setting up a Research Institution, much like the Royal Institute where he lectured on microwaves when he was young. More than 25 years had passed. Much water had flown down the Ganga since then. Bose received honours not only from his own countrymen for whom he was one of the pioneers of modern science in India. The British Government knighted him in 1917, the first Indian scientist to receive knighthood. (See chronology.)

It was not only Bose but several other stalwarts in India had realized the urgency of setting up Institutions in India, that would help India to surge ahead and get out of their intellectual servitude.

The Indian Institute of Science, the dream of Sir J. N. Tata, the great Industrialist, was founded in 1909 and a hundred years later, is considered

Fig. 11. The Bose Institute, Kolkata.

to be the best institution of research and higher learning in India. Tagore was dreaming of a University where great minds from all over the world could meet and he founded the Visva Bharati University in Santiniketan, West Bengal. Dr. Mahendralal Sircar had set up "The Indian Association for Cultivation of Science", referred to earlier and Sir Asutosh Mukherjee started the Science College in Calcutta which is next to the Bose Institution that was the dream of Bose which came true in 1917.

As always, money became a problem for all these dreamers. Bose gave his life's savings of Rs 400000 and prevailed on the Government to contribute towards the cost of the building and an annual grant which was granted with quite a bit of reluctance on the part of some members of the administration.[6]

In "The Voice of Life", Jagadish Chandra's inaugural address dedicating the Bose Institute to the Nation (30th September 1917), he began his speech with the following statement:

> *"I dedicate today this Institute — not merely a Laboratory, but a Temple ... Out of the very imperfection of his senses, man has built a raft of thought by which he makes daring adventures on the great seas of the unknown ... The personal,*

yet general, truth and faith whose establishment this Institute commemorates is this: that when one dedicates himself wholly for a great object, the closed doors shall open, and the seemingly impossible will become possible for him."

Bose wanted the research students to be totally dedicated in their research and live in the *ashram* (hermitage). Research in Physics, Plant physiology and even Psychology were on the agenda. Bose worked relentlessly and he expected his students to work likewise and is believed to have been harsh with them if they failed to keep pace with him. Bose also set up a similar Institute in Darjeeling where the climate was closer to the cold European climate and the flora and the fauna that were different from those on the plains.

The greatest contribution of all these Institutions set up by the great Indian scholars and patriots, to science education in India, was to help generations that followed to become competent scientists recognized all over the world.

Das Gupta[6] summarizes Bose's contribution to Indian Science as:

"Bose made pure science a credible occupation for Indians in the eyes of the world. In this lay his ultimate success and significance in the history of the western scientific tradition and in the social and cultural history of modern India."

1.22. His Last Days

Bose worked very hard in life and his achievements were not meager. What was remarkable about him was that despite all the impediments that he had to struggle against, he did not lose the zest for life. A brief account from Romain Rolland in 1927 when the two met for the first time in France, when Bose was almost seventy years old, may be quoted.[12]

"The life force and the brilliance that this man exuded for about three hours that we were together bears no comparison. He looked somewhat semitic, as if with Mediterranean blood in him, burnt complexion and two dry hands (hands of a genius) with deeply-trimmed nails, unbelievable youthfulness for his age, bubbling with the joy of life and capability of thinking, reminded me of Albert Einstein after his glorious discovery (1915)."

Bose maintained such a spirit for a long time. But a poem scribbled in his diary (date and author unknown, could have been written by him) reading as follows, may indicate the fatigue that may overcome even the most indomitable spirit.

The land beyond the sea!
When will life's task be o'er?
When shall we reach that soft blue shore
O'er the dark strait whose billows foam and roar?
When shall we come to thee,
Calm land beyond the sea?

Bose passed away in Giridh on 23rd November 1937 (survived by Abala Bose who passed away in 1951).

Tagore, also in failing health at that time, delivered a memorial address at "Basu Vignan Mandir" (the Bose Institute), on 30th November, the day

Fig. 12. Jagadish Chandra Bose (from a painting by Bikash Bhattacharya, courtesy, Ms. Parvati Bhattacharya and Birla Art Museum).

when the Institute was set up about 20 years earlier. His concluding sentence, so valid in today's context, was

> *"I offer my salutation to the illustrious founder of this Institute, humbly sitting by those who are deprived of the sufficiency of that knowledge which only can save them from the desolating menace of scientific devilry and the continual drainage of the resources of life, and I appeal to this Institute to bring our call to science herself to rescue the world from the clutches of the marauders who betray her noble mission into an unmitigated savagery."*

1.23. Bose the Writer of Science Fiction and Popular Science

It may not be known that J. C. Bose is acclaimed as one of the first science fiction writers of India. He was an avid traveler. Patrick Geddes provides accounts of his travels across India and traces his love for Nature and his love for his country to the extensive travels he undertook, not only visiting inaccessible shrines and temples in the country but studying people from different parts of India. Geddes recounts "that side of Bose's life and larger education ... which nerved him for his best work and for his Indian ambitions beyond his personal interests and achievements. Immediately after his marriage, he began, with his young wife, to devote the two annual vacations to seeing and knowing India and to realizing what India stood for. He tried to understand the mythologies and folklores of India and some of the stories out of the great Indian epics *Ramayana* and *Mahabharata* which almost all Indian children used to grow up with. The following is an attempt to translate one of his popular stories. In this, he tries to de-mystify the origins of the river Ganga which has been the life-blood of India and is considered the holiest of all rivers.

In Search of the Source of Bhagirathi

The Ganga flows past the house where we live. Ever since my childhood, I had built up a close friendship with her. At a particular time of the year, the river would be in spate; at other times she would dry up. I used to watch the high tide and low tide on her every day. The river seemed to me to be someone alive who kept changing. In the evening, I used to sit by her all by myself. The ripples would keep breaking on the river banks and sing a

murmuring song as she flowed by. As darkness descended and the noise of the world around would die down, I could hear so many voices in the murmur of the river.

"Ganga, where do you come from?" I used to ask the river.

"From the matted hair of Mahadeva", she would reply.

I would then remember the story of Bhagirath's ushering in of Ganga down to earth.

I have read many accounts and explanations of how a river is formed. But whenever I sat near the Ganga in the quiet darkness of the evenings, I would hear the same answer from her.

"I flow out of the matted hair of Mahadeva".

Once on the banks of the Ganga, I watched the cremation of some one very dear to me. It suddenly hit me that the shelter of love which I had cherished ever since I was a child had just gone up in smoke. The soul of love which nurtured me had disappeared to an unknown land. Doesn't one who leaves this world ever return? Does one disappear into eternity? Does life end with death? Where does one go after one dies?

Where is my beloved one today?

"At the feet of Mahadeva", I could clearly hear the answer in the murmur of the river.

"We go back where we come from. After a long journey away from home, we come back home." The river seemed to say as darkness closed in.

Whenever I asked the question: "Where do you come from, dear River?" I would get the same old reply, "From the matted hair of Mahadeva."

One day, I told Ganga, "Ganga, our close alliance goes back to so many years! You are my oldest friend. You have been so deeply involved in my life. In fact, you are very much a part of my existence. I do not know the source of your origin. I mean to travel along your course to see for myself where you come from."

I had heard that the snow-clad peak of the mountains in the North-West of our country is the source of the Jahnnavi.[c]

I started my journey across towns and cities, forests and hills and arrived at a place called Kurmachal, mentioned in our epics. Having traced the source of the river Saroju, I reached Danavpur. Then I crossed many hills and peaks and kept moving north.

One day, totally exhausted from my endless journey, I sat down. I could see a chain of mountains and deep forests around me. A huge peak, piercing

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[c] Jahnnavi: One of the many names of Ganga.

the sky as it were, stood in front of me shielding everything behind it. My guide said, "Your dreams will be realized if you can climb this mountain. See that silver thread down below. It turns into the mighty river Ganga and rushes down your country, at times flooding the banks on its way. If you can climb this hill, you will be able to see its source".

My guide suddenly exclaimed, "Look over there!"

"Jai Nadadevi! Jai Trishul!" he shouted.

As I climbed, the views in front of me that were obscured even a little while back, appeared as if a veil had been lifted. The blue sky stretched right across. Two snow-clad mountains stood, their heads raised high. One looked gentle and kind, like the mother earth in whose bosom all lives thrive, while the other was tall and sharp, like a firmly held spear, piercing through the earth and the sky.

I could see "Creation and Destruction" side by side.

"You have a long tortuous trek ahead of you. If you walk for two days, you will see the frozen river", said my guide.

Trekking along hills and forests, gorges and caves, I finally reached the valley of snow. The soft murmur of the river which I could hear all this time, suddenly stopped as if at the bidding of a magic wand. The fluid flow of the river had frozen into an icy silence. At places there were frozen waves as if the frolicking waves had been suddenly commanded to 'attention'. It seemed as if a great creator had used up all the crystals of the earth in landscaping this frozen ocean.

Huge mountains on both sides raised their heads aloft and innumerable trees right from the foothills showered their gifts of flowers. Water melting from glaciers wound its way and fell down into the valley. Nandadevi and Trishul were now plunged into a haze and could not be seen any longer. If I could cross the curtain of haze, the hills would be visible again.

I kept trekking along the frozen river. This river was coming down from Dhawalgiri. As it plunged, it broke boulders on the way and huge stones lay scattered all over the place. As I climbed further, from one boulder to another, the air became thinner and smelt of divine incense. Breathing became difficult. Overcome by exhaustion, I collapsed, unconscious, at the feet of Nandadevi.

Suddenly, thousands of conch shells roared aloud and in my daze, with eyes half-opened, I could see in the mountains and forests, an enormous puja had been arranged. Water poured down the huge spout of a holy pot, trees were offering their flowers and thundering sound of conch shells

reverberated all over. I could not be sure whether the sound was from conch shells or from boulders of ice rolling down.

I was thrilled and overwhelmed with joy when, looking ahead, I saw that the haze that had been covering Nandadevi and Trishul had now lifted, and around the peak of the Nandadevi there shone a glow that was difficult to gaze at. The smoke that rose from the lighted haze covered the sky. Is that then the so-called matted hair of Mahadeva? It covered the Nandadevi like a roof. Droplets of ice shining like diamonds fell, sharpening the Trishul and forming a crown of diamonds around the peak of Nandadevi. Shiva and Rudra, *the saver and the destroyer*, I realized the meaning of the myth. I could see in my mind's eye how water drops collect and make their journey to the sea and then come back here as vapor. The eternal cycle of creation and destruction was clearly visible.

Drops of water penetrate the bodies of these enormous mountains and break them. Boulders, so dislodged, roll down with thunderous sound. The water drops freeze to make a bed of ice below. As the broken boulders fall on the ice bed the water drops call at each other and say, "Come on, let us make a new world out of the bones of these boulders."

Billions and trillions of water drops combine their minute forces and push the boulders down. Valleys are formed. Endless friction turns the stones into dust.

From where I sat, I could see a number of huge stones piled up. Ice melts and turns into a water-flow carrying the stones along, forming towns and cities. If there is a desert *en route,* it is flooded and soil deposited on the desert become fertile with the bones carried with the water flow and soon the desert turns into a green pasture. Rain and water-flow, flush the earth and pour the wastes into the bed of the sea and there, unseen by humans, a new world is formed.

The water drops that flow into the sea are driven by the wind and drown the coastal lands, then they flow into the earth as a sacrifice to the eternal fire inside and the steam arising out of that *Yagna* break the crust of the earth and belch out fire as volcanoes. The earth shudders. Land sinks below the bed of the ocean; land masses from the bottom of the ocean rise to make new continents.

Water drops cannot rest even when they merge into the ocean. Heated by the sun, they rise again. Driven by wind and storm they go back to the mountains. They take a little rest as they lie on the beds of ice before they begin to flow again. It is an endless cycle.

Even now, when I sit on the bank of Bhagirathi, listening to the murmurs, I hear her give me the same answer to the same question that I have been asking her for years. But now I have no difficulty in understanding her.

"Oh, River, Where do you come from?"

I can hear her reply loud and clear now:

"From the matted hair of Mahadeva[d]*"*

Translated from the original (1894) by D. P. Sen Gupta.
(His mother died the same year.)

1.24. A Chronology

Jagadish Chandra Bose

A Chronology. 1858–1937 (Courtesy Bose Institute, Calcutta)

1858: 30th November: Born at Mymensingh, East Bengal — son of Bhagaban Chandra Bose and Bamasundari Bose.

1870: Admitted in St. Xavier's School, Calcutta after receiving his elementary education in a Vernacular School at Faridpur, East Bengal.

1875: Passes the Entrance Examination of Calcutta University in the First Division with a scholarship — joins St. Xavier's College, Calcutta.

1877: Passes the First Arts Examination of Calcutta University.

1880: Passes the BA Examination of Calcutta University. Leaves for England for higher studies.

1880–1881: Studies Medicine in London for a year.

1881: Enters Christ's College, Cambridge.

1884: Graduates from Cambridge (Natural Science Tripos) and passes the BSc Examination of London University.

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[d] Mahadeva — or Siva, one of the major gods of the Hindus. In one of his forms which is most common, Mahadeva holding a trident in his hand, wears matted hair with serpents round his body, his third eye on his forehead emanates light. Mahadeva sits on the Himalayas in meditation. As the myth goes, he received the Ganga in his matted hair (jata) to control her torrential flow.

1885: Appointed officiating Professor of Physics in the Presidency College, Calcutta.

1887: Marries Abala Das, daughter of Durgamohan Das.

1888–1894: Made permanent in the Presidency College with retrospective effect. Pursues scientific hobbies.

1894–1895: Gives a public lecture at the Calcutta Town Hall showing the possibility of signalling by short electric waves.

1895: Communicates to the Asiatic Society of Bengal his *first scientific paper* on "The Polarisation of Electric Ray by Crystals" published in its Journal — *Communicates*, through Lord Rayleigh, *his first paper to the Royal Society of London*, "On the Determination of the Indices of Electric Refraction", published in its Proceedings (Vol. 59, 1895).

1896: Conferred the Doctorate of London University.

1896–1897: First Scientific Deputation to Europe. Reads a paper before the British Association at Liverpool on "Complete Apparatus for studying the Properties of Electric Waves". Delivers his first Friday Evening Discourse at the Royal Institution, London, on "The Polarisation of the Electric Ray". Visits France and Germany and lectures before the Société de Physique in Paris and the Physikalische Institute of the University of Kiel.

1897: Rabindranath calls on Jagadis Chandra on his return home to offer him his congratulations on his successful mission abroad.

1900–1901: Second Scientific Deputation to Europe. Reads a paper before the International Congress of Physics at Paris (1900) on "De la Généralité des Phénoménes Moléculaires produits par l'Electricité sur la Matiére Inorganique et sur la Matiére Vivante". Meets Swami Vivekananda in Paris. Reads a paper before the British Association at Bradford on "The similarity of effect of electric stimulus on inorganic and living Substances" and exhibits there and in the Royal Institute, London, an "Artificial Retina" (1900). Demonstrates a new phenomenon on "Binocular alteration of vision" before the Physiological Society of London (1900). Works in the Davy Faraday Research Laboratory for two terms (1901). Reads a paper before the British Association at Glasgow (1901) on "The change of conductivity of metallic Particles under Cyclic electromotive variation." Delivers his second friday evening discourse at the Royal Institution,

London, on "The response of inorganic matter to mechanical and electrical stimulus".

1902: Gives a demonstration-lecture before a special meeting of the Linnean Society on "The Electric Response in ordinary Plants under Mechanical Stimulus". Reads a paper before the Société de Physique, Pairs, on "Sur la Reponse Electrique de la Matiére Vivante". Elected Member of the Société Francaise de Physique. Reads a paper on "Electric response in animal, vegetable and metal" before the British Association at Bradford. His *first book*, "*Response in the living and non-living*", published by Longman, Green & Co., London.

1904: A series of five papers on "Plant response" are not accepted for publication by the Royal Society. Decides to publish his investigations in form of monographs. USA Letters Patent No. 758, 840 issued for his Detector for Electrical Disturbances.

1904–1905: Devises a number of new apparatus revealing unsuspected phenomena in plant-life.

1906: His *second book, Plant Response as a Means of Physiologieal Investigation* published by Longman, Green & Co., London.

1907: His third book, *Comparative Electrophysiology*, published by Longman, Green & Co., London.

1908–1909: Third scientific deputation to Europe and America — Reads a paper on "Mechanical and electrical response in plants" before the British Association, Dublin. Visits America and delivers a series of lectures before the annual joint meeting of the American Association for the Advancement of Science and the Botanical Society of America at Baltimore, the Medical Society of Boston, the Chicago Academy of Sciences, the Torrey Botanical Club, the Western Society of Engineers at Chicago and at the Universities of Illinois, Ann Arbor, Wisconsion and Chicago on electrophysics and plant physiology.

1911: Presides over the Bengali Literary conference at Mymensingh and delivers an address on his researches and findings.

1912: Companionship of the Star of India (C. S. I.) conferred on him. Conferred DSc (Honoris causa) by Calcutta University.

1913: His fourth book, *Researches on the Irritability of Plants*, published by Longman, Green & Co., London. Delivers three lectures at the Punjab University.

1914–1915: Fourth scientific deputation to Europe and Anterica. Lectures before the Universities of Oxford and Cambridge. Delivers his third friday evening discourse at the Royal Institution, London, on "Plant autographs and their revelations". Visits Austria and lectures before a meeting of leading scientists in Vienna. Visits Germany and lectures at several universities. Lectures before the Royal Society of Medicine, London, on "The action of drugs on plants". Visits America and lectures at the principal universities; addresses the American Association for the Advancement of Science and the Botanical Society of America at Philadelphia, the New York Academy of Science, the Washington Academy of Sciences and the Botanical Society of Washington, the American Philosophical Society, the Natural Science Auditorium of the Iowa City, and at the Twentieth Century Club. Gives a demonstration lecture before the State Department officials in the Diplomatic Reception Room, Washington. Visits Japan and delivers a public lecture at the Wasede University. Retires from the Indian Educational Service (November 1915). Appointed Emeritus Professor of the Presidency College on full pay for five years.

1916: Delivers the inaugural address, entitled "From the voiced to the unvoiced" at the foundation of the Banaras Hindu University.

1917: Addresses the Faridpur Industrial Exhibition on the life of his father, Bhagaban Chandra Bose, who founded the exhibition fifty years ago. Knighthood conferred on him. Founds the Bose Institute in Calcutta, on the 30th November, his 59th Birthday, and delivers an inaugural address entitled "The voice of life" (printed elsewhere).

1918: Starts publishing regular research reports in the form of *Transactions of the Bose Research Institute, Calcutta*. The first volume appears under the title *Life Movements in Plants*". Delivers a lecture on "The unity of life" under the auspices of the Bombay University. Lectures at the Royal Opera House, Bombay, on "Invisible Light".

1919: Publishes "*Life Movements in Plants*", being Vol. 2 of the Transactions of the Bose Research Institute, Calcutta.

1919–1920: Fifth scientific mission to Europe. Gives a demonstration-lecture at the India Office under the president-ship of Arthur James Balfour. Lectures before the Universities of Cambridge, Oxford, Leeds, London. Awarded the honorary degree of LLD by the Aberdeen University.

Elected Fellow of the Royal Society, London, (13th May 1920). Addresses the Royal Society of Medicine. Demonstrates, before eminent

scientists, "Magnetic Crescograph" at the Physical Laboratory of the University College, London. Visits France and lectures at Paris before the Biological Society, Physiological Congress, and the Botanical Society. Lectures at the Rothamstead Experimental Station, England. Visits Sweden and lectures before the Physical Society of Stockholm. Visits Germany and lectures at Berlin before eminent Plant Physiologists. His biography, "*Life and Work of Sir J. C. Bose*", by Professor Patrick Geddes, is published by Longman, Green & Co., London. Publishes Vols. 3 and 4 of the *Transactions. Bose Research Institute* entitled, *Life Movements in Plants.* Publishes *Aryakta*, a collection of writings in Bengali.

1923–1924: Sixth Scientific Mission to Europe. Gives demonstration-lectures at the University College, London, University of Prague, at the Danish Botanical Society, the University of Copenhagen, before the Imperial College of Science, London and the Royal Society of Medicine, London, on "Assimilation and circulation in plants". Speaks at the India Office, London, before a distinguished audience, including the Prime Minister (Mr Ramsay Macdonald), Lord Hardinge (ex-Viceroy) and Mr. George Bernard Shaw, on the "Phenomenon of the growth of plants." Publishes Vol. 4 of the *Transactions of the Bose Research Institute*, entitled "*Physiology of the Ascent of Sap*". His fifth book, *The Physiology of Photo-synthesis,* is published by Longman, Green & Co., London. Visits France and lectures at the Natural History Museum and the University of Paris. Nominated a member of the League of Nations Committee on Intellectual Co-operation. Delivers the Convocation Address at the Punjab University, Lahore.

1925: Lectures on "Invisible light" at the Bose Institute. Delivers the convocation address at the Banaras Hindu University.

1926: His *sixth book, The Nervous Mechanism of Plants*, is published by Longman, Green & Co., London. Seventh Scientific Mission to Europe. Lectures before the University College, London, at the Royal Society of Medicine, the Royal Society of Arts and the British Association at Oxford. Visits France and lectures at the Sorbonne and the Natural History Museum, Paris. Visits Belgium and lectures before the Foundation Universitaire, Brussels, the King of the Belgians presiding over the meeting and conferring on him the Decoration *of Commandeur Ordre de Leopold*. Attends the first meeting of the Committee on Intellectual Co-operation of the League of Nations at Geneva and lectures at the University of Geneva before a

distinguished gathering of international scientists, including Professors Lorentz and Einstein.

1927: His *seventh book*, *Collected Physical Papers*, is published by Longman, Green & Co., London. Presides over the Fourteenth Indian Science Congress at Lahore.

Eighth Scientific Mission to Europe. Lectures at some of the southern universities of France. His *eighth book*, "*Plant Autograph and their Revelations*", published by Longman, Green & Co., London. Speaks on "The mechanism of life" at the Kingsway Hall, London, in connection with the International Homeopathic Congress. Addresses the International Conference on Education at Locarno on way to attend the League of Nations meeting at Geneva. Delivers the Convocation address at the University of Mysore. Lectures at the Madras University on "Invisible light" and on "Surge of life". His *ninth book, Motor Mechanism of Plants*, is published by Longman, Green & Co., London.

1928: Ninth Scientific Mission to Europe. Lectures at the University of Vienna. Delivers a series of lectures at the University of Munich. Attends a meeting of the League of Nations Committee on Intellectual Co-operation. Lectures at the Geneva School of International Studies on "The Plant as a sentient being". Visits Egypt at the invitation of the Government of Egypt and lectures at the Royal Geographical Society of Egypt. Delivers the Convocation Address at the University of Allahabad and conferred the honorary degree of DSc Addresses the All-India Medical Conference at the Bose Institute. His 70th Birthday celebrated in Calcutta on November 30.

1928. Professor H. Molisch of Vienna comes as Visiting Professor to the Bose Institute.

1929: Tenth and last Scientific Mission to Europe. Gives a demonstration lecture at the India Office on "The Revelations of the Unvoiced life of Plants" before scientists and politicians. Attends a meeting of the League of Nations Committee on Intellectual Co-operation. His *tenth book*, "*Growth and Tropic Movements of Plants*", published by Longman, Green & Co., London.

1931: Awarded "Shree Sayaji Rao Gaekwad Prize and Annuity" for three years. Edits Vol. 6 of the Transactions of the Bose Research Institute and Civic address presented by the Corporation of Calcutta, headed by Mayor Subhas Chandra Bose.

1933: Edits Vol. 7 of the *Transactions of the Bose Research Institute* (1931–32). Visits Baroda and delivers a series of lectures on his researches and discoveries. Conferred the honorary degree of DSc by the Banaras Hindu University.

1934: Gives a discourse on "Indian aspirations and achievements" during the Golden Jubilee Celebration of the Gaekwad of Baroda. Delivers the Convocation Address at the University of Nagpur. Edits Vol. 8 of the *Transactions of the Bose Research Institute* (1932–33).

1935: Edits Vol. 9 of the *Transactions of the Bose Research Institute* (1933–34). Conferred the honorary degree of DSc by the Dacca University.

1936: Edits Vol. 10 (1934–35) and Vol. 11 (1935–36) of the *Transactions of the Bose Research Institute.*

1937: 23rd November: Dies at Giridih (South Bihar). Funeral in Calcutta.

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Chapter 2

The Millimeter Wave Researches of J. C. Bose

by M. H. Engineer

"I found in him (Bose), a dreamer, and it seemed to me, what surely was a half-truth, that it was more his magical instinct than the probing of his reason which startled out secrets of nature before sudden flashes of his imagination. In this I found our mutual affinity but at the same time our difference, for to my mind he appeared to be poet of the world of facts that waited to be proved by the scientist for their final triumph, whereas my own world of visions had their value, not in their absolute probability but in their significance of delightfulness." [Rabindranth Tagore[1]]

"The wireless telegraph is not difficult to understand. The ordinary telegraph is like a very long cat. You pull the tail in New York, and it meows in Los Angeles. The wireless is the same, only without the cat." [Albert Einstein[2]]

2.1. Introduction

The quotations at the head of this article have been chosen with some care, for two reasons. First of all, they reveal a common purpose. It is easy to see what that purpose is if we remember that poets and common people alike know how hard it is to write good poetry and, then, ask ourselves "Why should doing science be any easier than writing poetry?"

The quotation from Einstein is typically homely: he used the homely form in order to assure lay people that they, too, could grasp difficult truths. The equations and experiments of science were alien things to lay people. Abolishing that alien-ness was the purpose behind the well-known, and usually splendid, use that Einstein made of homely images.

Tagore's words stem from a similar spirit. He felt that there was a gap between the sciences and the arts. The gap was mirrored in the gap between

the poetry that he wrote and the science that his friend, Bose, did. But he wanted to close it: equal devotion to the sciences and the arts was what he wished from the university that he established, at Shantiniketan. Those with intimate knowledge of his accomplishments know that.

I now turn to the second reason.

2.1.1. *A small story of knowledge*

Are there no limits to what we can discover? The unity of all knowledge is feebly emphasized in science writing today. Galileo may have seen it very differently. "Philosophy", he said, "is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures without which it is humanly impossible to understand a single word of it. Without these, one is wandering in a dark labyrinth."[3] But who reads Galileo any more? In any case, how far was he right in using the phrase word "continually open"? The "small story" in the title of this subsection refers to answers to that question.

The story concerns the familiar metaphor: "Knowledge is like an expanding sphere". It says that the metaphor can be read in two ways. In the first way, you focus on the sphere as the only important thing. In the second way, you say that the many meeting places between space and the sphere are the important things.

Votaries of the first way see counting the fruits of growth as the only new intellectual activity that a growing knowledge needs, beyond the ones that got the growth going in the first place. Greed may lead them to that view, or something else may. But, whatever the reason, they see the absence of the word "space" in the metaphor as a harmless thing, and not as an important error of judgment in the underlying thoughts.

Votaries of the second way are followers of Pascal.[c] Pascal denied that fruit counting was singularly important, so he imported space into the metaphor. The move allowed him to focus on the places where space and the sphere meet, and hold fast to the fact that those many meeting places changed as knowledge advanced — expanding spheres necessarily travel through ever-new regions of space. When he had done all that, he declared

[c] Blaise Pascal (1623–1662), a French polymath.

that those meeting places mirrored the many problems of growing knowledge, in short, that the more knowledge grows the more it comes face to face with new and increasing amounts of the unknown.

That uncommon, and uncommonly subtle, reading of the familiar bare metaphor alerts us to what we may call the problem of knowledge.

2.1.2. *Its application to science*

Does the metaphor apply to the case of scientific knowledge? The question is obvious.

A little thought shows it to be two separate questions, for the science that existed before the scientific method was discovered, and for the science that has been produced after the method was discovered, by Galileo Galilei.

The answers to it are:

(i) The metaphor barely applies to pre-discovery science because of the rather haphazard ways in which that science was done in those days.
(ii) It applies — in spades — to the science that has been done after the discovery of the method.

Why does it apply so well to modern science? Has the method of science radically and irrevocably changed the way in which science is done? Is this because the old ways of doing science could not have yielded the fruits that the methodical way of doing it has, in fact, yielded? Is this because there is an unbridgeable gulf between the old ways of doing science and the new way of doing it?

Anyone living after the discovery of the scientific method could easily have recognized all of those things. Note that they are not the sought-for reasons and they are not where the strength of the metaphor lies.

The strength of the metaphor lies in the fact that it gives us a clear idea of the limitations of the scientific method: what it can do for science and what it cannot. It says that the scientific method can do what it has, in fact, already done for science, which is to open the road to prosperity for it. But it simply does not say that the road is going to be an easy one.

The discovery of the scientific method does not reduce the actual doing of science to a manageable set of simple tasks. More bluntly, as befits the age that we live in, profits are not guaranteed to those who invest their money in science. But surprise, almost surely, is guaranteed!

Several crisp lessons follow from that fine piece of reasoning:

(i) We should not panic over the vast differences that exist between today's science and science as it was in, say, the 17th and 18th centuries.
(ii) We should expect great distances to exist between the mature and unified thing that our science is and the motley collection of infant sciences that their science was, in contrast to ours.
(iii) We should realize that any history of modern science must consist, almost entirely, of the stories that relate to how those great distances were bridged.

I shall deal here with one of those stories — the story of radio science, not with all of it but with a crucial part of it, and, within that crucial part, principally with J. C. Bose's contributions to the development of that part. Bose made two major contributions. He discovered millimeter waves and he elucidated almost all of their properties. But, before turning to that task, it is useful to briefly outline the status that radio science, and particularly millimeter wave science, has today.

2.2. Radio Science Today

2.2.1. *Millimeter waves in modern life*

2.2.1.1. *At airports*

"EU airports to strip visitors visually." This headline appeared in the "Spotlight" section of 2nd October 2008 edition of the Asian Age, a daily newspaper that is published in the city of Kolkata. The section appears at the top of the "International" on page 7.

Why is the headline relevant to today's radio science? A clear answer to the question appears lower down on the same page, in the body of the article whose substance the headline attempts to capture. It is contained in the following words, "according to a draft European Commission regulation, the new *millimeter wave* imaging scanners are to be used "individually or in combination, as a primary or secondary means and under defined conditions" to provide a "virtual strip search" of travellers, reports The Telegraph".

The connection with modern living is obvious. Millimeter waves are a big part of radio science. Radio science is essential for airport security. Airports are essential to modern living.

2.2.1.2. *In scientific research*

Going further, millimeter waves have made radio astronomy possible for aspiring scientists. Radio telescopes allow astronomers to do what they could not do with optical telescopes, like observing the universe's radio galaxies, for instance. Radio astronomers have used those waves, and their closest cousins — the microwaves — to confirm that there was a Big Bang. They have measured the spectrum of the relic radiation left over from that singular event, and have even shown us that the Big Bang did not occur at a single space–time point but was spread out over a space–time region.

2.2.1.3. *At home*

Here, even more can easily be said. We talk, easily, about the radio universe in our homes. The food that we eat as we talk has been cooked, more easily than we talk, in microwave ovens. We use the ovens as readily as our ancestors used smoky, wood-burning fires to cook the food they ate as they sat under the starry sky. It is also the case, for all the radio science that our scientists know, that the common man knows much less about the patterns that the stars make in the night sky than his ancestors did.

2.2.1.4. *Anywhere*

I turn, finally, to mobile communication. I do so for two reasons. J. C. Bose's work is integral to it, and it has transformed the lives of millions of Indians.

The India into which J. C. Bose was born barely had trains. Bose traveled to Europe on board steam ships. We have no record that he ever boarded an aeroplane. Did he ever speak to his mentor, Lord Rayleigh, in England over the telephone? The answer is "No". Submarine cables had been laid across the Atlantic Ocean during his lifetime. But the Indian Ocean was still without them.

The point of that little recitation is plain enough: barriers make history, and poor communication ranks high in the "Big Barriers that made Indian history" stakes. More than any other factor, it was the absence of good communication that made India into a land of very many different peoples.

Indians, today, quarrel over the formula "Communication equals unification". They can claim to do so, legitimately. But they must accept the negation of the formula as true, even if they do so with the greatest regret

that their past was not very different because the mantra "No communication, no unification" is pure gold.

Mobile communication has changed the lives of the Indian people, "if not substantially then in considerable measure".[1] The Indian poor go today, as their ancestors did, wherever they can earn a living. They now stay connected to their homes. For millions of village folk, mobile phones ease the pains that enter their lives as agriculture becomes unviable, industrialization goes up and migration to crumbling and inhospitable cities becomes the only option. The increasing dislocation of village life is a time bomb. Mobile phones help to defuse it. For common people, they are a very great boon. For the authorities, the fact that they are that boon is a very great relief.

2.2.1.5. *A small conclusion*

The list of the ways in which radio science enters our lives is not just one more lengthy list. The time taken to prepare and publish such a list is likely to be so long that new uses will have entered in the interval. Lewis Carroll's "It takes all the running one can do to stay in one place" seems to apply to radio science today! Table 1 is a list of the acronyms in common use in mobile communication today.

2.2.2. *The common man and radio science*

Most people will grant that radio science is something more than just a useful gadget. They will also agree that it is indispensable to modern living. Yet, they will say that they think about radio science about as often as they think about the many gadgets that they use daily ... meaning that they hardly ever think about it! If pressed further, they will mutter "Marconi" and, may be, "Trans-atlantic signaling", and change the subject.

What happens when you ask most people whether wirelesses came before radios or after them, or whether there was a radio science before Marconi, or whether people tried to send signals by radio over distances shorter than the trans-atlantic distance, before Marconi made that distance famous?

Their answer to all such simple queries is that they are meant for quizzards.

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[1] The words are in Jawaharlal Nehru's Independence Day (1st August 1947) speech. The full sentence in which they occur reads "The time has come to redeem that pledge, if not substantially, then in considerable measure".

Table 1. A short glossary of terms used in mobile communication.

3G	3rd generation mobile standard
AMPS	Advanced Mobile Phone System
Bluetooth	Short-range wireless communication
BS	Base Station
CDMA	Code Division Multiple Access
CODEC	Coder and Decoder
Email	Electronic mail
EMS	Enhanced Messaging Service
GPRS	Global Packet Radio Service
GSM	Global System for Mobile communication
Infrared	A wavelength range for electromagnetic waves
Internet	A global network
ISP	Internet Service Provider
MMS	Multimedia Messaging Service
PDA	Personal Digital Assistant
PIN	Personal Identification Number
PSTN	Public Switch Telephone Network
QoS	Quality of Service
Roaming	Enables users to receive calls abroad
RFID	Radio Frequency Identification
SIM	Subscriber Identity Module
SMS	Short Message Sevice
Talk-time	Battery lifetime for talk before recharge
UMTS	Universal Mobile Telecommunication System
UWB	Ultra Wide Band
WAP	Wireless Application Protocol
WLL	Wireless in the Local Loop

While they can name the ancestor sciences from which radio science evolved — as it happens, correctly — as electricity and magnetism, they will reply "somehow" when asked for a broad timeline of that evolution.

They know little about the present state of electromagnetism (the name given to the unification of electricity and magnetism), even though electromagnetism is the master science that radio science is an important part of. They probably know even less about the state that the sciences of electricity and magnetism were in around the end of the 18th century, when they could, in very proper ways, be said to have been the ancestors of radio science.

2.2.3. *Some things that we scarcely know*

The end of the 18th century is a convenient date for us, for several reasons.

The first reason was that much more was known about electricity (the word comes from the Greek word "electricus", for amber) by the end of the 18th century, than the ancient Greeks knew about the subject when they rubbed pieces of amber with dry pieces of silk. Even more was also known, at the same time, about magnetism. "Even" is an apt word to use for the knowledge of magnetism because the sophisticated, medieval Chinese scientists knew a lot more about the subject than the ancient Greeks knew about electricity.

The second reason was that despite the added knowledge, the two sciences were still distinct. We may know electromagnetism to be a very great unification. But a scientist at the end of the 18th century simply could not have ever guessed that the phenomena of electricity and magnetism were at all related, let alone very deeply intertwined. The fact that there was also a connection between those two sciences and the science of light was beyond their dreaming. How vast the gulf that needed to be bridged was, then!

The third reason was that the century that began when the 18th century ended was a period of great scientific discovery, for the sciences of electricity and magnetism, and for radio science. The first hint of a connection between electricity and magnetism was discovered almost two decades later, when Hans Oersted took a magnetic needle that he knew to be mounted so that it could rotate freely about a fixed axis (in other words, a standard magnetic compass that every school going child knows), placed it near a copper wire, passed an electric current through the wire and saw that the needle was deflected. Fixed electric charges attracted or repelled each other whereas moving charges, or electric currents, deflected magnetic needles. The first great step in magnetism, beyond what the Chinese knew about it, had been taken in 1819.

The fourth reason was that people like Hans Oersted must have worked very hard to take 18th century science from the rudimentary state that it was in then to the state that five-star radio science is today. One reason for saying so is that the people involved were, for the most part, ordinary people — only two of them, Michael Faraday and J. C. Maxwell, were giants of the caliber of Isaac Newton or Albert Einstein. Another reason was that the gap between the states of the electric and magnetic sciences at the close of the 18th century and the state that radio science is in today is, really, huge. The point is worth a little thought, if only in order to register the contrast

between those unrecognized pioneers and the many "don't knows" today who enjoy the fruits of what those pioneers did.

2.2.4. *Bridging the gulf and Bose*

A gulf existed between what was known about electricity and magnetism in the early 19th century and what we know, today, as modern radio science: it was not bridged steadily.

Bridge-building was very slow during the first half of the 19th century because the links connecting the two sciences were both subtle and unfamiliar. It picked up speed once Michael Faraday came up with the idea of lines of forces, and still more speed when Maxwell, using Faraday's ideas and discoveries, decided that electricity and magnetism were ripe for unification, and produced his theory of electromagnetism.

For all that, radio science remained a far cry — from its status today, the science is nothing when it is not practical — till nearly the end of the 1880s. The major advances came after that year, in a big rush, over the last two decades of the 19th century.

The most significant chapter in those advances began with the discovery of millimeter wave electromagnetic radiation, in 1895, and ended a few years later, when the properties of those very special waves fell, one by one, before a new kind of experimental science. Novel techniques were used to make the initial discovery. Delicate experiments followed. The techniques and the experiments combined to write the chapter, rapidly and successfully. Both of them were, largely, the work of one man, J. C. Bose. Bose studied the properties of millimeter waves with a gusto equal to the gusto with which he discovered them.

We shall be largely concerned with his work. We shall see how the short space of time that he needed for making the discovery marked him out as an unusually capable experimenter with exceptionally clear intentions. The same characteristics will appear more clearly in the many subsequent studies that he made on the properties of the waves.

The main focus of those studies can be summed up in the very simple terms that Bose himself used:

> *"That the waves had all the properties that light was known to have, and that the theory of electromagnetism said that they ought to have."*

The studies were exhaustive because the devices that Bose invented in the course of making them were both very plentiful and very useful.

They were, in fact, so plentiful and useful that Bose could easily have claimed for himself that his work had turned the tasks of generating, manipulating and detecting millimeter waves — each one of those very different tasks had been extremely difficult things to do before he first appeared on the scene — into almost routine affairs, without appearing to be thought at all immodest.

The discoveries and inventions of Bose were widely recognized by his fellow scientists. They found them to be both significant and surprising. The quality and quantity of his inventions, and the completeness of his studies made recognizing their significance an easy job.

The surprise, however, lay elsewhere, in the circumstances under which Bose lived and worked at the time. The long litany of those very constricting circumstances must begin with the fact that Bose lived amongst a people who had long lost their once great scientific traditions. This is how Rabindranath Tagore described the deadly effects of that loss:

> *"In a large forest, the trees shed their dry leaves one by one in profusion thus making the soil underneath fertile. In a country where there is continuous research in science, knowledge of it in fragmentary bits is being spread constantly. This is how ones hearts' soil is quickened, becoming fertile with an alive feeling in science. It is the loss of this that has left our minds unscientific. We feel the impoverishment not only in our education but also in our field of occupation where we are bowed with frustration"* — Rabindranath Tagore in 'Bishwa-Parichaya' quoted from its English version titled "Our Universe" translated by Indu Dutt.

J. C. Bose also referred to the following, at the end of a lecture that he delivered before the Royal Institution in London:

> *"The land from which I come did at one time strive to extend human knowledge, but that was many centuries ago. It is now the privilege of the West to lead in this work. I would fain hope, and I am sure I am echoing your sentiments, that a time may come when the East, too, will take her part in this glorious undertaking; and that at no distant time it will neither be East nor West, but both the East and the West, that will work together, each taking her share in extending the boundaries of knowledge, and bringing out the manifold blessings that follow in its train."*

Tagore's sad words express his deep longing for complete change. Bose, in contrast, is hopeful that the change that his compatriot longed for would, in fact, happen when the word "renaissance" applies to what Bose was doing in those days.

The applicability of the word "renaissance" becomes clearer the more we learn about the trying circumstances of Bose's life at the time. He had to earn his living as a physics teacher in a small college. The college had no tradition of scientific research. It therefore lacked the means to provide him with the facilities that his research required, and lacked the desire to do so. The direct result was that Bose had to work in a cramped space, and had to work completely without direct contact with any of his scientific peers, all of whom either lived far away in Europe, or even further away, in the USA.

The surprise that his peers felt continues today, as we realize the extent to which his work nourishes today's communication science and technology.

2.3. Before Radio, a Prologue

The nature of modern scientific knowledge, as it has previously been explained (see Sec. 1.2), is such that it either grows cumulatively, which is what happens most of the time, or suddenly shifts track. It shifts track when a reigning paradigm is unable to accommodate new facts.

That being so, the best way to begin assessing the importance of new work in any field of science is to obtain as good a knowledge of as large a fraction of the relevant work that preceded, and stimulated, those entering the field, as possible. Only then can we assess how much they improved upon the existing knowledge.

My principal sources in this regard are *A History of the Theories of Aether and Electricity, Volume I*[4] by Edmund Whittaker and *History of Wireless*[5] by T. K. Sarkar and his collaborators. I am unaware of any better sources.

I start with that part of the history of Electromagnetism that can be said to have helped give birth to radio science. I shall not enter into the details of radio science, nor say much about electromagnetism. I do this for three reasons: diligent readers will know, most of the time, how and where to find the details that interest them; the literature, on both subjects, is vast; I am not writing a substantial history of the subject, let alone a complete one.

2.3.1. *Electromagnetism before Bose: a timeline*

2.3.1.1. *Maxwell's memoir*

8th December 1864: Maxwell,[6] reads a memoir on "A Dynamical Theory of the Electromagnetic Field" before the Royal Society of Edinburgh. He has worked on constructing the theory for about a decade.

The now famous equations are all there. They are not there in the form that we are familiar with today, of four coupled partial differential equations. Those equations and that form will appear later. They first appeared in Maxwell's 1873 book,[7,8] together with the familiar scalar and vector potentials, and even the Coulomb gauge.

We know all that today, in hindsight and with 150 years of continuous effort to guide us. But what about Maxwell's listeners, who are not so lucky, and what do they feel? They are without almost everything that we have. They are unfamiliar with a new kind of theory. They are forced to hear it for the first time. Finally, they are told that what they have heard is a complete unification of electricity and magnetism.

It seems that they are both repelled and attracted by what they have seen and heard. Take the abstractness of the equations. They cannot digest it in one go, so it repels them. But the startling conclusions that flow from that abstractness are another matter. Who can ever ignore them? It is as if the combination is too much for them to think about.

Those terse comments need a little explaining:

(i) Fields are not part of the view that most scientists have of the physical world. Their view of that world is the same as Newton's view of it. Newton had put down his view in the Principia.[8] Force is the central element in that view, and gravity is the paradigm force. The force of gravity acts between all material bodies. It does so no matter how far apart the bodies are, and does so instantaneously. Change something here and now, and the whole universe feels the change, right away. The forces of everyday life are not like that at all. They are contact forces. Gravity goes to the other extreme. Newton had recognized that the extreme view of force that he was forced to accept was, well, extremely absurd. In a letter that he wrote to his theologian friend, Bentley,[9] he said,

> *"It is inconceivable that inanimate brute matter should, without the mediation of something else which is not material, operate upon and affect other matter without mutual contact ... That gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed*

[8] Oliver Heaviside was responsible for the vector form of the equations.

from one to another, is to me so great an absurdity that I believe no man who has in philosophical matters a competent faculty of thinking can ever fall into it."

(ii) Given that eloquent description of instantaneous-action-at-possibly-infinite-distances, it is easy to see what fields are. They are conditions of space and time that exist over extended regions of space and time. Except for that property, a field of force is really like the contact forces that we know from everyday experience. The value(s) that a field takes depends on where we choose to put our measuring instruments, and when we choose to look at them. Experiments with electrical currents, magnets, iron filings, and polarized light were the things that inspired Michael Faraday (1791–1851) to introduce the concept of a field into science.[h] It represented a tremendous leap for science, a forward leap as it turns out!

Of course, the experiments only measured the forces between charges and currents. Seen in isolation, such measurements suggested action at a distance. But Faraday did not see them in that way. For him, they were not the only reality of electric and magnetic phenomena. Electric and magnetic fields could exist in parts of space where neither charge nor current existed. The postulated fields would resolve the absurdity of distant and instantaneous action into a sequence of local effects in the following way. Change a charge or a current somewhere at some time and the electric and magnetic fields in the immediate neighborhood of the charge or the current is immediately modified. Then, the undiscovered nature of the fields forces the neighboring modifications to communicate the changes away, in all directions, from the charge or the current, even when the modifications need to travel into regions of space that are devoid of gross matter. The modifications, when they arrive at a distant charge or a distant current, exert the force that experiment measures. Thus, force is the end result of a sequence of intermediate actions, all of which are contact actions. The benefit of the field is that it preserves action by contact.[i] Its cost is the cost of introducing a new hypothesis.

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[h] Faraday wrote, in his 1831 notes, "By magnetic curves, I mean lines of magnetic forces which would be depicted by iron filings."

[i] It is worth noting here that the worries about gravity that Newton had expressed in his letter to Bentley were to be taken care of less than a century later by yet another set of fields, by an as yet unborn Albert Einstein. But, we need not worry about those fields here.

Maxwell faced that cost. He saw what had to be done to complete Faraday's ideas. He had to describe the combined dynamics of the hypothetical electric and magnetic fields. The equations in the 1864 memoir are that description.

The equations predict that waves of oscillating electric and magnetic fields can travel through empty space. They also predict the speed at which those waves will travel in empty space.

Maxwell had calculated what the speed would be, from two experiments. The first experiment measured the force between two electric charges, which had the same value, but were separated by a fixed distance in space. The second experiment measured the force between two currents with the same value, that flowed in the same direction in fixed, parallel wires located at different places. The first experiment defines the unit of electrostatic charge, while the second defines the unit of electromagnetic charge. But since current is defined as the flow of charge, it follows that the ratio between the units of electric charge thus defined must be a fixed number.

When Maxwell computed the numerical value of the ratio between the values of the two unit charges, he obtained a speed of 310 740 000 meters per second, which was the measured speed of light.

That was a strange and unexpected, result. It was strange because the speed of light was measured in an "all optical" way, meaning that none of the usual paraphernalia of electric and magnetic experiments played any part at all in its measurement: charges and currents were absent; the voltmeters and ammeters used to measure charges and currets were also absent; and so on.

Two entirely electromagnetic measurements and one entirely optical one added up to the obvious conclusion:

> *"The agreement of the results seems to show that light and magnetism are affections of the same substance, and that light is an electromagnetic disturbance propagated through the field according to electromagnetic laws."*

Given that conclusion, why did his listeners feel uncomfortable?

The answer to that question lies in the fact that Maxwell said nothing about the proposal that obviously followed from his conclusion, which is: "can one generate light by manipulating electric currents and charges?"

His listeners had good reason to feel uncomfortable.

2.3.1.2. *After the memoir*

In 1879, 15 years after that puzzling December day, Maxwell died. He was only 48 years old. His theory was unconfirmed by experiment, which was not surprising because no experiment has been done. The English experimenters did not seem to understand his theory. The continental experimenters did not seem to like it. Action at a distance dies hard!

The theorists are a contrast. They are hyper-active in England, and in Europe, they grapple with paper and pencil with the troubling "abstractness" of the equations. They grapple with them by making elaborate mechanical models of them. Maxwell, Thomson, Kirchoff, Bjerknes, Leahy, Fitzgerald, Helmholtz, and Hicks all participate in this work.

2.3.2. *Radio's pioneers*

2.3.2.1. *G. F. Fitzgerald in 1882*

George Frances Fitzgerald is an ardent Maxwellian and a Professor of Physics at Dublin University. His paper "On the possibility of originating wave disturbances in the ether by means of electrical forces"[10,1] outlines a scheme for constructing an electromagnetic wave generator of sufficient power. The entire scientific community, he feels sure, will accept Maxwell's revolutionary theory as correct if his proposed scheme works. The scheme, which is quite simple, says:

> *"Get hold of a Leyden jar. Charge it. Discharge it into a loop of wire. The arrangement will generate oscillating currents of very high frequency."*

That, in today's terminology, requires us to charge a capacitor with a voltage that is large enough to "breakdown" the air between its plates (electrically), i.e., discharge it with a spark. The discharge will be oscillatory. We recognize that because we know all about tuned circuits and natural frequencies. We also recognize Fitzgerald's "loop of wire" as a magnetic dipole antenna.

But no one knew all that in Fitzgerald's time, so who could be sure that the arrangement would work? True, Benjamin Wilson had recognized the possibility that the current generated by such a discharge would be oscillatory in 1750.[11] But Fitzgerald went much further. He did not just

[1] The details of Fitzgerald's comments at the *Roy. Soc. (Dublin)* meeting of 1983 are given on p. 100.

predict how the current in a wire connected to the capacitor would behave but claimed that the oscillatory current would generate Maxwell's predicted waves in the air between the capacitor plates, and that the waves would spread out from that source into space, and reach far away places after some time.

2.3.2.2. *Hertz in 1889*

Helmholtz urges Hertz, who works at the University at Karlsruhe, to do Fitzgerald's proposed experiment. Accepting the challenge, Hertz discharges the output of a spark gap generator, via a Ruhmkorff's coil into a dipole antenna. He observes how each generated spark sets off an accompanying, but less intense spark across the air gap between the *open* ends of an otherwise similar wire loop kept some distance away. The loop serves as his detector.

Hertz spent nearly two years in making his system perfect. Finally, in January 1888, he reported:

> *"The question on which the thing turns is to prove that electromagnetic effects (for the sake of simplicity, let us say electrical effects) propagate through the air space at a finite, definite, demonstrable velocity and not as an instantaneous action at a distance without time elapse. Since the velocity is very nearly that of light, 300 million meters per second, and since the effects were previously barely observable a few meters away, the proof was not easy. But I think I have it for certain."*

He went further. He decided to establish that Maxwell's waves were present in the space between the source and the detector. He did this by setting up standing waves in the space between them. He detected the standing waves by moving the loop antenna along the imaginary line that "joins" the source to the detector.

The waves have a wavelength of 66 cm. He called them "electric waves", and showed that they travel along wires (and through air) with speeds that are very close to the speed of light. He diffracted them using a slit. He established that his waves are linearly polarized, which was a feat — and a first — because no known *light* source produced polarized radiation at the time. He constructed rotating polarizers from sets of appropriately spaced parallel metal wires fixed to a frame. He wrote[12]:

> *"As soon as I had succeeded in proving that the action of an electric oscillation spreads out as a wave in space, I planned experiments with the object of*

concentrating the action and making it perceptible at greater distances by putting the primary conductor in the focal line of a large parabolic mirror."

"Large" meant very large. His mirrors were made from sheet zinc and mounted on timber frames. They were huge, crude and costly while their horizontal and vertical apertures were about 1.2 and 2.0 meters respectively and their focal length and depth of focus were a mere 12.5 cm and 70 cm respectively. They could not have produced anything like a parallel beam. Nevertheless, Hertz claimed that his waves obey the laws of reflection and refraction.

He made a far-reaching comment:

"It is a fascinating idea that the processes in air which we have been investigating represent to us, on a million fold larger scale, the same processes that go on in the neighborhood of a Fresnel mirror or between the glass plates used for exhibiting Newton's rings."

The comment can be taken to signal the birth of radio science.

2.3.2.3. *A chain of investigators in 1889–1894*

Lodge, Righi, Popoff and Fleming carried Hertz's work forward. Lodge produced powerful high frequency waves on wires (today's transmission lines). Marconi's teacher, Righi, started working with frequencies of 3 and 10 GHz. A drive towards shorter wavelengths was on. Why was this so?

The problems raised by unwanted reflections from the walls of the room were the reasons. People started to work on developing spark gap generators at higher frequencies. Righi, Lodge and Fleming worked at microwave frequencies. The work that they did paved the way for wave-guides.

For instance, Oliver Lodge demonstrated radiation from circular waveguides on 1st June 1894 at the Royal Institution in London.

2.4. Radio Science, an Interlude

Today, radio means entertainment, for most people. Mostly, it has been taken for granted by us. We have forgotten its great impact on human life. But we would easily remember that impact if we were seamen.

Think of ships at sea, or of ocean-going boats before there were ships. Both kinds of craft have been plying for a long time. How terrifying was a

seaman's job thought to be, in the pre-wireless remote days? The expression "all at sea" provides us with an answer.

Ask the question "What did the phrase 'maritime communication' mean before the days of radio?" and the answer would be that it meant the use of colored flags to communicate a very limited number of very simple messages to people whose flags you could see waving about.

This happened in clear weather. What did seamen do when the day was foggy? They either made, or heard noises using a bell or a foghorn! At night, they looked out for a lighthouse if the night was clear and you were close to shore, and prayed if it was not clear. Ships far out at sea were utterly desolate places then.[k]

It was not easy for ships close to shore either — not when there was fog and the risk of running aground.

Radio ended that isolation, and removed most of the danger. Its use has saved thousands of lives. It saved them even when Morse code transmission was all that was available, during the first two decades of radio's use. The sinking of the Titanic, on 15th April 1912, highlights this aspect of radio's value to ocean vessels.[13,l]

How did radio come to be used in navigation, and what is the connection between knowing that and Bose? The answers to those two questions come in four parts. Firstly, it was first reported on 10th April 1891 in

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[k] "Until the dawn of this century, ships great and small sailed for distant ports and, once they had passed over the horizon, were lost to the world until weeks or months later when they were again sighted on shore. Once out of sight of land those who went down to the sea in ships belonged to another world — a world of stark loneliness and utter silence. Ships burned or foundered in storms with not so much as a whisper reaching land to tell their fate. The crew of a sinking or burning ship fought their battle for life, silently and alone. Wireless telegraphy with its magic powers was to wrest from the sea its ancient terror of silence and to give speech to ships which had been mute since the dawn of navigation." — [Karl Baarslag, *SOS to the Rescue*, 1935].

[l] "One of most dramatic sea disasters was the sinking of the *Titanic* in the North Atlantic on the morning of 15th April 1912. The *Titanic*, along with the *Carpathia*, which picked up the survivors, was staffed by Marconi Wireless operators, and Marconi shore stations along the Canadian, Newfoundland, and US coasts handled most of the communication as the *Carpathia* slowly made its way to New York City. In addition, many inland stations tried to get information about the disaster, which in this unregulated era resulted in extensive interference and confusion".

The Electrician, an English journal.[14] Secondly, Bose was an avid reader of the journal. Thirdly, the date of the report tells us that the suggestion appeared on the scene before Marconi, so that the phrase "ahead of its time" certainly applies to it. Fourthly, the date signals the beginning of Bose's interest in the topic. The following was suggested:

> *"Point-to-point microwave communication would take care of the problem of navigation."*

Remember that microwaves had not been invented. Heinrich Hertz may have shown in 1889 that the waves that he produced could transmit and receive signals, but that was over *short* distances only. The unknown writer in *The Electrician* was suggesting that a lightship could use *microwave* radio signals to communicate much further, and through fog, between ships at sea and land. Lighthouses would become electric houses. The idea was a remarkable one.

It would come to life more than 50 years later when, driven by the needs of the Second World War, the technology for producing microwave signals was developed. The development was as remarkable as the idea. It spoke of the close connections between advances in science and the need for war machines, and the need for the money interests that are connected with those machines, the so-called military-industrial complex that the world still lives with.

Even more remarkable are the two reasons that the writer gives for choosing microwave frequencies. Firstly, mist prevented the use of light for point-to-point communication between a lighthouse and a ship at sea because the particles in the mist were conductors of electricity. Also, the frequencies of light's electromagnetic oscillations were far too large.

The first reason was unavoidable. But the effect of the second one would be lessened if the frequency of the signal could be lowered. But it was difficult to determine to what value. It could not be lowered to the frequency of Hertz's waves because wavelengths of a foot and more would require constructing huge prisms and reflectors, and every sort of difficulty with diffraction and interference would surface. Waves in the millimeter wavelength range, on the other hand, would be ideal. Such waves, the writer added, would not only pierce a fog but also, probably, a brick wall. He did not say how one could produce the waves. J. C. Bose would produce them, in 1895. He would also send them through a brick wall, and others, a few years later, as we shall soon see.

2.5. Detecting Radio Waves in the Early 1890s

The drive to shorter wavelengths made Hertz's wire loop detectors useless. A new detector was needed. An enterprising French physicist, Edward Branley[15] made such a detector, by filling a case with iron filings and shaking them around until each grain is in intimate contact with its neighbors. Place the object in the path of electromagnetic waves, he said, and you will detect the presence of those waves.

Branley probably argued from the known fact that two metal particles in close contact will stick together when a *direct* current of electricity passes through them because of the heat that the passage of current generates. As a result, the contact resistance between the particles changes, i.e., falls. Extrapolating from that, Branley argued that his iron filings-filled tube would serve as a detector of the oscillating electric field present in electromagnetic waves: the waves, when they fell on the detector, would change its DC resistance by an amount that would depend on the intensity of the waves. The idea would work provided the change in resistance was large enough to detect. Because it was, and because nothing else was available, everyone jumped onto the bandwagon.

2.6. Bose's Decisive Year

Bose's decisive year was when Hertz died in 1894.

2.6.1. *Bose's early researches*

Bose began experimental work in Kolkata, in a small space adjoining a bathroom at the Presidency College, Kolkata, which he converted into a laboratory.

His early objectives were very simple. They appear clearly in the first paper that he wrote. The paper, which was submitted to the Asiatic Society of Bengal in May 1895, and read a few months later in 1896,[16] refers to the well-known optical phenomenon of double refraction, and asked: "Does its analog exist for Hertz's "electric rays"?"

The reply was immediate:

> *"It was thought that the analogy between electric radiation and light would be rendered more complete if the classes of substances, which polarize light, were also found to polarize the electric ray. The two phenomena may be thought*

identical if the same specimen is found to polarize both the luminous and the electric rays."

But how was the objective to be realized? Hertz's electric waves would not do. Their 66 cm wavelengths meant that very large crystals were needed to observe birefringence. But Bose was not deterred. He developed a new radiator at much smaller wavelengths (Fig. 13):

"Electric oscillations are produced by sparking between hollow hemispheres and a small interposed sphere ... There is now no difficulty in obtaining an oscillatory discharge ... effective sparks have a peculiar smooth sound, whereas non-oscillatory discharges give rise to a peculiar cracked sound."

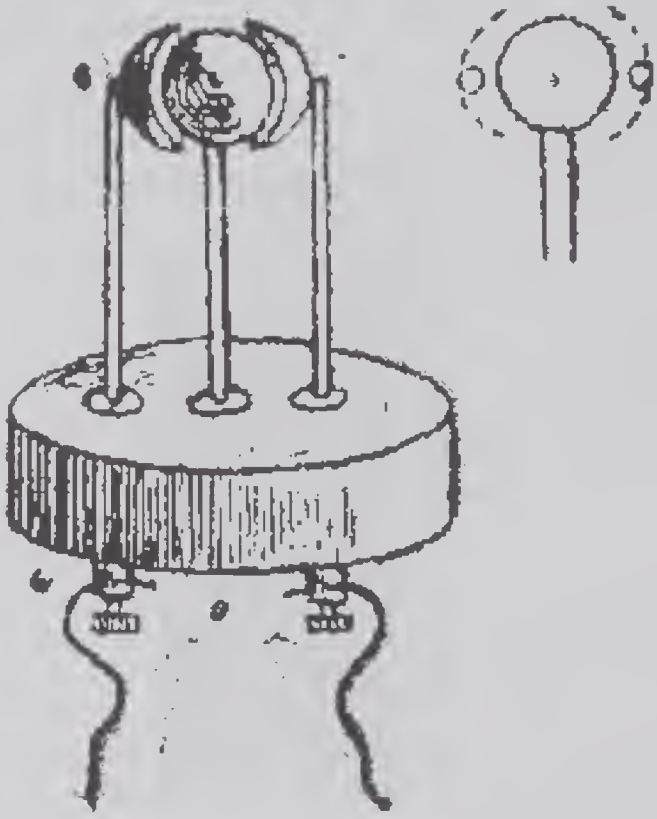


Fig. 13. Bose's radiator.[m]

[m] Found in Ref. 21, p. 2 and Ref. 38, p. 29.

The arrangement allowed him to meet his objective:

> *"I have, however, succeeded in obtaining polarization effects with crystals of moderate size. This I was able to do by reducing the wavelength of electric waves to about 5 mm."*

It is worth emphasizing that a wavelength of 5 mm can hardly be measured by the crude method of standing waves, that sufficed for Hertz.

The reduction in wavelength allowed Bose to reduce the dimensions of his quasi-optical appliances, so that he could focus his radiation using a small parabolic reflector, polarize it by means of a simple wire grating, study the indices of refraction of air, water, glass, pitch and sulphur, and show with great accuracy that the many other properties demanded by standard electromagnetic theory to be true.

Bose also invented a new detector, which he called the Spiral Spring Coherer (Fig. 14). The device consisted of sets of tiny springs held together

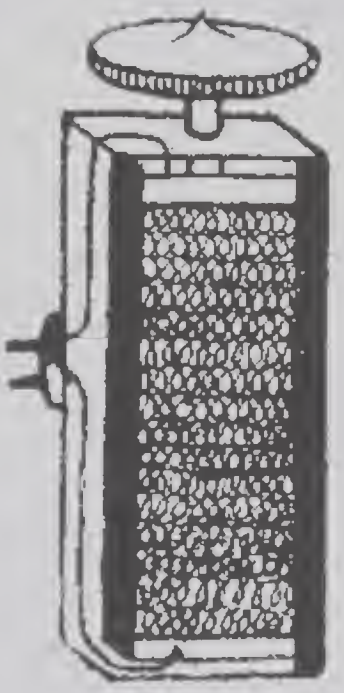


Fig. 14. Spiral spring coherer.[n]

[n] Found in Ref. 21, p. 4 and Ref. 38, p. 33.

side by side under pressure. A simple screw arrangement allowed the pressure to be varied. Detection of electromagnetic waves took place at the many points of contact between the coils of the springs. D. T. Emerson[17] had described the device as a "space irradiated multi-contact semiconductor using the natural oxide of the springs. It was a great improvement on Branley's crude device.

The Electrician reported Bose's early discoveries on the existence of birefringence, at millimeter wave frequencies, in natural crystals like Tourmaline and Hematite and artificially-produced bundles of jute fibers,[18] and on strain-induced birefringence in artificially-cast pieces of pitch, a rectangular paraffin block, one side of which is chilled and stratified rocks.[19]

1895 was also the year in which Bose was first invited to demonstrate his discoveries publicly. The demonstration took place at Kolkata's Town Hall.[20,o] It went very well. The bell rang that afternoon, not by hand but by remote control, and a shot was fired from a loaded pistol although no one pulled the trigger. Both were done automatically via the agency of his unseen waves. He showed that his rays could not only travel through air as easily as light does but that they could also travel through wood, the human body in the person of the Governor of Bengal province, and even through walls made of stone. They traveled a distance of 75 feet. They would travel further if the radiators that he used to generate them could be made more powerful and the detectors that he used to measure them made more sensitive. Both tasks, given the damp climate of Bengal, were not easy.

News of Bose's success traveled to England. In 1896, the *Daily Chronicle of England* reports: "The inventor (J. C. Bose) has transmitted signals to a distance of nearly a mile and herein lies the first and obvious and exceedingly valuable application of this new theoretical marvel."

2.6.2. *At the Royal Institution, London in 1897*

A friday evening discourse at the Royal Institution[21,p] on 29th January was one of the high points of Bose's visit to Europe. He used the discourse to set out the advantages of using millimeter waves at length:

> *"For experimental investigation, it is also necessary to have a narrow pencil of electric radiation, and this is very difficult to obtain, unless waves of a very*

[o] The exact date of the Public Lecture at the Town Hall, Kolkata is not known. D. M. Bose gives it as 1894–1895. See Ref. 20.

[p] The discourse, at the Royal Institution of London, was given on 29th January 1897.

> *short wavelength are used. With large waves diverging in all directions and curling around corners, all attempts at accurate work is futile. ... All these drawbacks were ultimately removed by making suitable radiators emitting very short waves. The three radiators here exhibited give rise to waves of approximately a quarter, one and a half inch in length."*

He also exhibited what we recognize as an entire millimeter wave bench. The bench was first seen in public on 21st September 1896 when the following was read before the British Association.[22,q]

> *"On complete apparatus for the study of the properties of electric waves,"*

contains a radiator, a spectrometer circle, a plane mirror and a cylindrical one, a totally reflecting prism, a device that he called "collecting funnel", which we recognize as a pyramidal electromagnetic horn antenna, and a spiral spring detector (Fig. 15). The entire apparatus fitted into a 60 cm × 30 cm × 30 cm case, giving us a good idea of the precision with which it was put together.

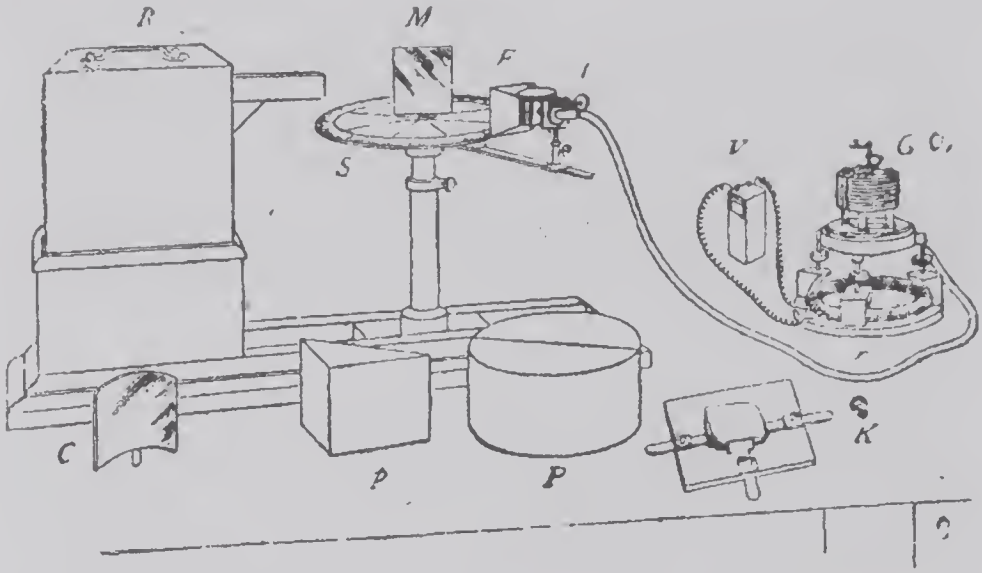
During the discourse, Bose demonstrated that millimeter electric waves performed the following:

(i) When directed at a block of pitch, the waves pass through it.
(ii) When directed at a heap of irregularly-shaped pieces of pitch, the waves show "an opacity similar to the opacity of powdered glass to light".
(iii) They obey the laws of reflection to an accuracy far better than Hertz's waves.
(iv) They are refracted by prisms of sulphur and ebonite, both of which are easy to cast.
(v) An 8 mm air layer at a glass-to-air interface suffices for getting total internal reflection.
(vi) The index of refraction of glass for electric rays is 2.04 (compared to 1.52 for Na-light).

He continued to use the spiral spring coherer.

Five papers, of increasing sophistication and daring, were published in 1897, while he was visiting England. Their contents stretched from describ-

[q] The British Association lecture is referred to in the same reference given for Ref. 18, pp. 46–58; see also Ref. 22.



R, radiator ; S, spectrometer-circle ; M, plane mirror ; C, cylindrical mirror ; *p*, totally reflecting prism ; P, semi-cylinders ; K, crystal-holder ; F, collecting funnel attached to the spiral spring receiver ; *t*, tangent screw, by which the receiver is rotated ; V, voltaic cell ; *r*, circular rheostat ; G, galvanometer.

Fig. 15. The complete millimeterwave bench.[r]

ing a new technique for measuring the wavelength of his rays, to determining the direction in which they were polarized, to measuring the refractive index of glass accurately, to showing that the conductivity of some of the substances that polarize the rays is anisotropic, to an ingenious arrangement — of which more later — for observing total internal reflection (see above).

The following quotation is taken from his Royal Institution lecture:

> *"These great regions of invisible light are now being slowly and patiently explored. In time, the great gaps which now exist will be filled up, and light-gleams visible and invisible will be found merging one into the other in unbroken sequence."*

It made plain what his goal was, for the science he had kick-started so successfully. The whole of the electromagnetic spectrum, that continuously infinite ladder of frequencies had to be first generated, and then turned on

[r] Found in Ref. 21, p. 53 and Ref. 38, p. 28.

to the material world in order to study the electromagnetic properties of that world. His goal was "explore, explore, explore."

2.6.2.1. *An assessment*

The new radiators marked Bose as a first-class experimenter. The polarimeters made him the father of microwave analog optics. The spiral spring coherer was a good invention. The Town Hall demonstration was interesting. But it did not establish the superiority of electric rays for practical communication since light easily travels 75 feet through air.

In fact, a few years later, Marconi made radio frequency waves (with wavelength much longer than Bose's waves) travel 3 miles across the Salisbury Plain and across the Atlantic. Marconi knew about modulation and put a telegrapher's key into his circuits.

2.6.3. *Further developments*

2.6.3.1. *1897*

The first development was theoretical, and was not made by Bose. It occurred in February 1897, when Rayleigh's classic theoretical paper.[23] "On the passage of electric waves through tubes or the vibrations of dielectric cylinders" appeared in the Philosophical Magazine.[24] The mode problem in waveguides was then completely solved.

The question arised: "Did Bose's British Association talk influence Rayleigh to tackle the mode problem?"

2.6.3.2. *1898*

In 1898, Bose discovered that twisted bundles of jute fibers (Figs. 16 and 17) rotate the plane of polarization of electric waves.[25] The direction of rotation depends only on the sense of the twist: it flips when the twist flips, but remains the same if the ray reverses direction. Bose had discovered the geometric phase, anticipating the 1987 experiment of Tomita and Chiao[26] by 90 years.[28] He thought and proved by simple experiments that macroscopic bundles of jute modeled the molecular behavior of molecules of sugar in solution. The fact that there were two kinds of sugar molecules follows from the fact that the plane of polarization of light rotates in opposite directions

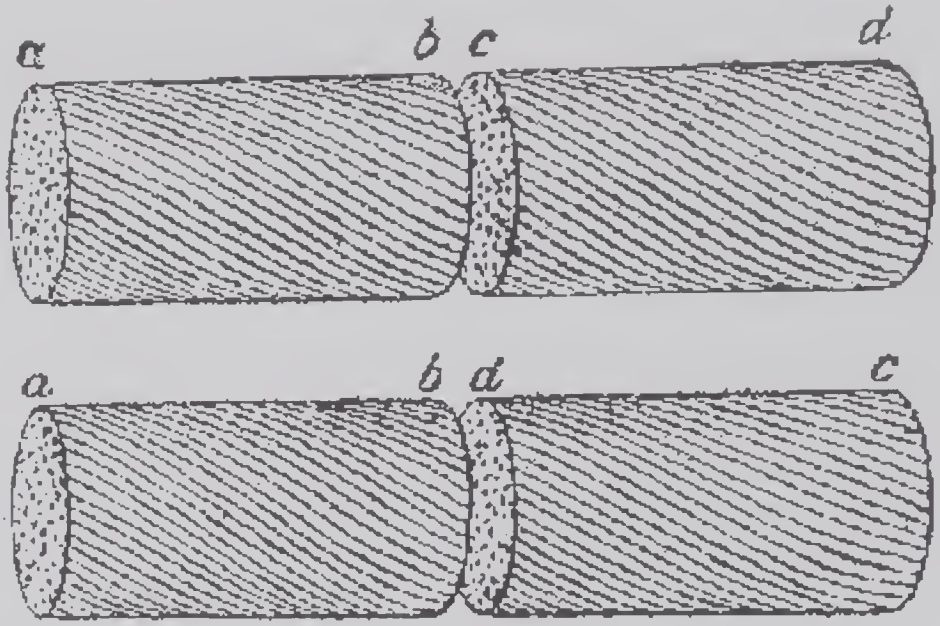
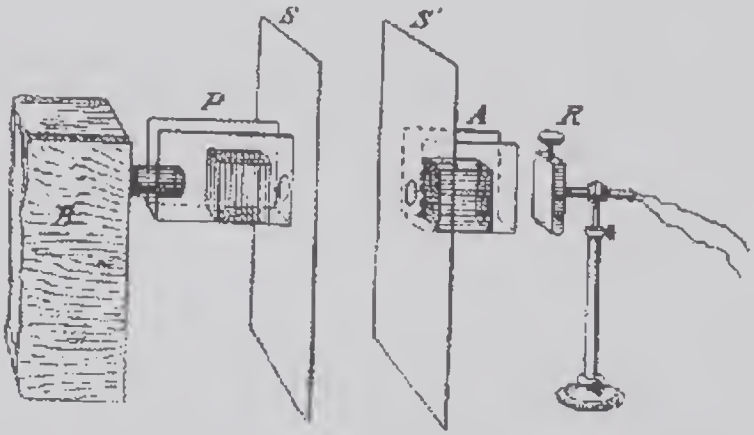


Fig. 16. Jute elements.[s]



Polarisation apparatus. B, the radiating box ; P, the polariser ; A, the analyser ; S, S', the screens ; R, the receiver.

Fig. 17. Polarization apparatus.[t]

[s] Found in Ref. 21, p. 102 and Ref. 38, p. 34.

[t] Found in Ref. 21, p. 99 and Ref. 38, p. 33, Fig. 9.

when one or the other kind of molecule alone is present in the solution. Bose's ingenious twisted bundles of jute, which he easily twisted in mutually opposite directions, thus mimicked the behavior of sugar solution. That was the first step in the microwave modeling of atomic processes. The whole field that Bose initiated seemed to be in for a revival.

2.6.4. *An assessment*

Ramsay[12] said that Lodge's use of a hollow cylindrical tube enclosing his emitter in 1895 is a precursor of today's wave-guides.[14] But Bose used hollow tubes of square and cylindrical cross-section for the same purpose between 1895 and 1897, and to much greater effect. Apropos of these technical advancements, Ramsay observed, "In radiating to free space from the open end of a hollow pipe they found a directive radiator unknown to optics". He added, "Bose was to make the next significant step", by using pyramidal electromagnetic horns as receiving antennae. We see Bose reasoning then as a trained microwave engineer would do today. If he increased the collecting area, he would increase the sensitivity with which he could detect the Maxwell waves.

Comment was almost superfluous regarding the ingenious ways he devised to generate millimeter waves. But comment was certainly very much needed regarding the methods that he used to receive them. We easily forget the invisibility of radio waves, as we forget the fact that "eyes" to receive those waves, as our eyes receive light, were completely unknown then. The spiral spring coherer was just such an eye. Bose improved upon it subsequently.

2.7. Bose's Work on Detectors

2.7.1. *Realizing that good communication needs sensitive detectors, Bose converted the "coherers", which were a heap of metal filings in loose contact between two metal electrodes, into delicate "spiral spring coherers" (see Fig. 14)*

Bose laboriously studied how these complicated devices worked, in an era when science recognized conduction and insulation as the only macroscopic electrical properties that a system of many electrons embedded in a bulk material could have (the "nano" world had not been thought of then). When semiconductors were unknown because quantum mechanics was unknown, he showed that a single point contact on a metal plate to be the most sensitive detector of all. He used many materials in this device. He measured how

the current through it varied with the applied voltage as a function of the pressure exerted on the point contact.

The materials fell into two groups,[24] a "positive" group in which the current increased when radiation was absorbed and a "negative" one, in which the current decreased. For example, iron was positive and potassium was negative. It was argued, in the then standard coherer theory that the metal particles that were in local contact in the device were fused together by the electric field that fell on them, and that this made the contacts between them more conducting. The observed decrease in the resistance (increase in the current) of the entire coherer was explained in this way. But the case of potassium showed this could not be correct.

The genius of Bose, and his great patience were evident from the fact that he moved towards single contact devices. This is what allowed him to classify the electrical properties of different metals into two distinct groups. What started out as a search for a more efficient detector of millimeter wave radiation ended up as a study of the surface properties of metals by that very radiation (see Fig. 18).

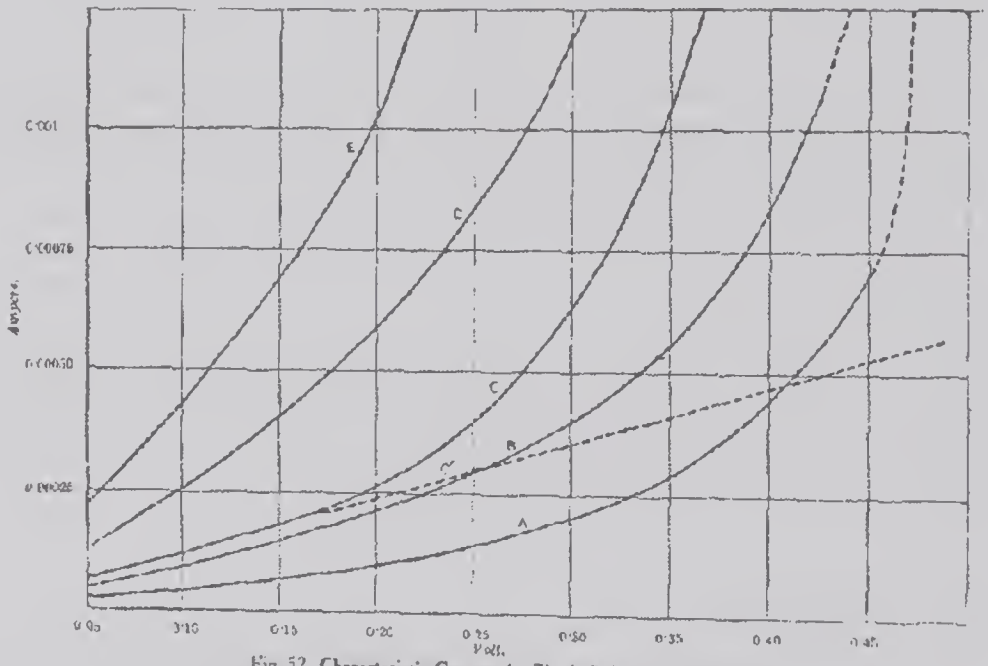


Fig. 52. Characteristic Curves of a Single Point Iron Receiver.
A, B, C, D, E are different curves for different initial currents, C' is the curve for a constant resistance.

Fig. 18. Graph.[u]

[u] Found in Ref. 21, p. 105, graph and Ref. 38, p. 32, graph.

Fig. 19. Photo.[37]

His masterpiece, made from galena, could detect the entire EM wave spectrum lying between millimeter electric waves and violet light. He called it an "Electric Eye" and patented it.[27]

Figure 19 shows a photograph of two of Bose's point contact detectors.

2.7.2. *An assessment*

Pearson and Brattain[28] correctly credited Bose with the use of semiconductor crystals for detecting radio waves. Brattain knew what he was saying. Along with Schokley and Bardeen, he received a Nobel Prize for inventing the transistor.

2.8. Conclusion

An article published in *Science and Culture*[29] by A. K. Sen assesses in considerable detail the impact of Bose's work on modern developments in

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[37] Found in Ref. 38, p. 33.

millimeter wave science and technology. I only wish to add three points to that assessment:

(i) A multi-beam receiver was constructed and installed in 1996 at the National Radio Astronomy Telescope at Kitt Peak, USA. It works at 1.3 mm, using a local oscillator that feeds eight channels. It couples the oscillator to each of the eight feeds optically. Local oscillator power is critical to efficient reception of distant radio signals, from all over the universe. To meet this critical requirement, John Payne made a millimeter wave attenuator for each of the eight feeds using a design by J. C. Bose (two 45 degree prisms separated by an air gap).[30] Payne's engineering drawings look like the ones in Bose's 1897 Royal Society paper. He referenced them, most generously. What Bose did one hundred years ago remains useful today.

(ii) According to T. P. Pradhan,[31] Bose should be recognized as the discoverer of Tunneling in 1897, while doing his pioneering experiments. Since its discovery in the quantum domain, the word "tunneling" has become part of common scientific parlance. But the phenomenon is typical of any wave motion. This is well illustrated in Vol. 2 of the famous *Feynman Lectures in Physics*.[32] Using an arrangement identical to Bose's, Feynman argues that if light is actually a wave, then total internal reflection cannot truly exist. Observing that the experiment is impracticably hard to do using light signals (because their wavelengths are so small), Feynman goes on to say, "but it is easy to demonstrate with three centimeter waves". No credit is given to Bose's pioneering work, which was documented in Sommerfeld's famous textbook on Optics.[33] Leakage of waves on the far side of a total internal reflection barrier is the signature of tunneling.

(iii) What was technologically impractical in optics when Feynman wrote his book has been done.[34] A Japanese group wanted to test a theoretical claim[35] that questioned the doctrine that it is impossible to simultaneously observe the wave and particle aspects of any quantum entity. To do so, they used an optical version of Bose's experiment and studied single-photon tunneling across a total internal reflection barrier. Both papers cite the 1897 paper of Bose.

I close with two comments about attitudes. Feynman's neglect of Bose is typical of post-war physicists. This was not true of the earlier physics textbooks. Just to quote one example, J. J. Thomson, in his foreword to the

collected works, wrote that Bose's work "marks the revival in India, of interest in researches in physical sciences".[36]

On the other hand, and very creditably, the electronics engineers have not followed the physicists. They have handsomely recognized the work of all the so-called Hertzians — Bose, Lodge, Righi and Marconi etc. (see Ref. 37 for example). The new generation of textbook writers in physics would do well to follow their electronic brothers and sisters, instead of blindly copying what previous physicist writers have done. Bose deserves no less. Who knows that the labor required to make good the previous neglect may prove that he deserves even more!

2.9. Bose's Legacy

The belief that much of our national life is rooted in developments that began in 19th century India continues to endure. It is a legacy. Amitava Ghosh has expressed it eloquently by describing the great Indian film maker, Satyajit Ray, as "a river in an unbroken chain of aesthetic and intellectual effort that stretches back into the mid-19th century" and adding the words "a chain in which I too am, I hope, a small part", to that finely turned phrase.

The belief was expressed in another form, at a three-day symposium that was held on the occasion of the 100th anniversary of Bose's galena detector patent at the Bose Institute, in Kolkata,[38] starting on 29th March 2004. The name given to the symposium was "Acharya J. C. Bose: The Scientific Legacy". It could hardly have been more specific or pertinent.

For what is a legacy other than a thing handed down by a predecessor or predecessors, to a successor or successors, which is how *The Oxford Dictionary of Difficult Words* defines the word? The dictionary then cites "the legacy of centuries of neglect" as an example that fits the definition.

The example also fits the educated Indian's scientific legacy at the time of Bose's birth in 1858. The country once had a living scientific tradition, which allowed it to invent the decimal system of arithmetic notation and Kanad's atomic theory, and to discover the medicinal uses of the organic herbs and the inorganic metals etc. All of those remarkable achievements aroused the interest of foreigners, many of whom were drawn deep into the country's cultural orbit. Even Prafulla Ray remarked in *A History of Hindu Chemistry* of the Arabs, "it had become part of completing one's liberal education to travel to India and learn the sciences first-hand".

But he also went on to remark in the same book, "all this was changed when the Brahmans reasserted their superiority on the decline or expulsion of Buddhism".

Indeed, Indians had lost the scientific heritage of their ancestors long before Bose was born and, far from recovering it on their own, preferred to wait until an Englishman, William Jones, handed it to them, on the proverbial platter.

On the other hand, Calcutta University, which was founded in 1857 supposedly on the model of the University of London, reserved just one half of a subject for physics in its B.A. examination in 1896. Bose pointed this out in a talk on "The promotion of the advanced study of physics in India", delivered in the same year before the Royal Society of Arts. He had by then established an international reputation for himself as an experimental physicist of exceptional originality and skill.

Given those facts, there is little need to elaborate on the difficulties under which Bose worked, except for two points.

1. Bose joined the Presidency College in 1885 as a Junior Professor of Physics, against fierce Departmental opposition, at only a third of the salary that his English colleagues drew. The figure was arrived at, by officialdom, by first "noting" that Indians, in the Raj's Education Service, normally drew two-thirds of an Englishman's salary, and by the fact that the appointment that was offered to Bose was an "officiating" one. Jealousy ensured it had to be, and because all "officiator's" only got only one half of a "regular's" salary. Notice that this was the fate of an Indian scientist at a time when 100 000 pounds sterling could be spent on a single laboratory in Germany. It was also the case that there was not a single scientific instrument maker in the country at the time.

To add to Bose's woes, Indians were supposed to be "metaphysical" types who lacked all aptitude for science. Of course, the criticism was without any merit. But Bose was young and talented and it wounded him deeply. Indeed, he refers to the slur repeatedly in his speeches and writings. This completes the first point.

2. The second one asks, "How did Bose respond to the undoubtedly severe difficulties that he faced?" He could have succumbed to his lot, as any ordinary Indian could have, and, having done so, very properly cited simple prudence as his justification. But he chose the path of struggle instead. That fateful choice, and more so the attitude that it was based on, set the tone for the rest of his career. It led him to great successes and, it is necessary to add, more struggles. It is sobering to think about the choices that he made then,

a few years after the International Symposium on Bose's legacy that I have already mentioned.

A few words about Bose's 1904 patent are needed. The patent that was granted to Bose, by the US Office of Patents was for a "Detector for Electrical Disturbance". What is so significant, in today's WTO-dominated scenario, about a over-100 years old patent with an innocuous sounding name?

The short answer to that, in two parts, says first of all that the Patent was remarkable because it took the very talented Bose the better part of a decade to do the very hard work that led to it and, secondly, that it was the world's first patent on a semiconductor device, even though no one at the time knew it.

Semiconductors make possible the computer on which I write this article. They are at the very heart of the Internet and today's computers. The list of the uses of semiconductors is, truly, very long, even longer than the list of the uses of millimeter waves. But the world had to wait almost half a century after Bose's patent before these unique materials could be discovered, in all their marvelous complexity. An outstanding team of scientists had to be brought together, given the many years and money that they needed, and left alone to do the job.

Bose, on the other hand, worked at a colonial college where he had to teach, examine, run laboratories, administer, and be many things to very many people. It is unsurprising, therefore, that he saw semiconductors — he never used the name — very simply, as materials that detected wireless waves most efficiently.

He knew very well that he had discovered a new class of such materials. But lack of time and the need to invent a more efficient detector for wireless waves did not allow him to study them in any other light. He worked, like most inventors do, by tedious trial and error, towards a specific goal. On the other hand, the later discovery team, three of whom shared a Nobel Prize in Physics for the work they did, was driven by the desire to know more. They were engaged in "blue skies" research.

What Bose did, he did alone, with little support, utmost perseverance and enormous skill. His was the solitary way, their's the collective. Both ways worked well, as they have often worked throughout the history of science.

The one patent that Bose took out formed only a very small part of the man's many achievements: the comment holds even more strongly for the "who really discovered wireless communication" question that the name of Bose is associated with.

We must, therefore, attempt to see all of the man's many achievements, and attempt to place both him and the achievements in the context of the times in which he lived — try, in a word, to see the whole man. How else can we assess the legacy that he left behind, or identify those who he took to be his inheritors, or those who actually were his inheritors, or determine how successful the actual inheritors have been, in putting their inheritance to good use?

That is going to be a rather unconventional exercise. It will involve the detectors that Bose made, semiconductors then and now, millimeter waves in communications and astronomy, patents and IPR issues today, Bose's researches on plants, plant electro-physiology then and now, life and non-life, Bose as a literateur and, finally, Bose and the Bengal Renaissance, all things that are part of the Bose legacy. It is to that end that I offer one more story about Bose.

All thinking Indians know that Rabindranath spent years pursuing a new system of universal education for Indian children. Few know that the pursuit was also a strong point of contact between the two men. Rabindranath, who based his system on a child's innate curiosity, which he sought to enhance and shape till it grew, as the child grew, into a strong, life-long interest in nature's ways, held alienation from nature to be the worst of all man's alienations.

What about Bose? Did he share Rabindranath's vision of the India that was yet to be? Did he share the poet's wide human sympathies? I think he did. For, in a letter that he wrote to the poet from London on New Year's Day 1903, he said, in part, "I am always thinking of your school and the more I think, the more I get convinced that it will be a national university one day".

"Your school" refers, of course, to the Brahmacharya Ashram at Bolpur. The school became Vishwabharati University, some twenty years later.

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Chapter 3

Reflections on the Many-in-One: J. C. Bose and the Roots of Plant Neurobiology

by V. A. Shepherd

"You cannot conceive the many without the one."
[Dialogues Parmenides 166, Plato d. 347 B.C.E.]

"What seems to you to be many is one."
[Bahaudin Naqshband d. 620 B.C.E.]

"The real is one. The wise call it variously."
[Rig Veda ~1500 B.C.E.]

3.1. Abstract

As one of the world's first biophysicists, J. C. Bose (1858–1937) extended his specialist knowledge of the physics of electromagnetic radiation into insightful experiments on the life-processes of plants. He invented unique, delicate instruments for simultaneously measuring bioelectric potentials and for quantifying very small movements in plants. Working with touch-sensitive plants such as *Mimosa pudica*, with plants that perform mysterious spontaneous movements, such as the Indian telegraph plant *Desmodium*, and with "ordinary" plants and trees, Bose concluded that plants and animals have essentially the same fundamental physiological mechanisms. Plants have a well-developed nervous system. All plants co-ordinate their movements and responses to the environment through electrical signaling. All plants are sensate, neuronal organisms, actively exploring the world, and responding to it through a fundamental, pulsatile, motif involving coupled oscillations in electric potential, turgor pressure, contractility, and growth. Bose's contention that plants have an electromechanical pulse, a nervous system, a form

of intelligence, and are capable of remembering and learning, was not understood or accepted in its time. However, a hundred years later, concepts of plant intelligence, learning, and long-distance electrical signalling have entered the mainstream literature. Sir J. C. Bose was far ahead of his time, as a progenitor of the emerging contemporary field of plant neurobiology.

3.2. Prologue

Darjeeling bustles with tourists in the warm month of April. By day, the impassioned sound of bargaining fills the streets, as pashminas, sweaters, trinkets, jewellery, fine teas, and hand-painted thangkas change hands. By night, this enthusiastic commercial hubbub is replaced by an altogether different sound, as bells echo and monks chant hauntingly into the valleys.

Shops also do a brisk trade in post-cards, inevitably depicting the Himalayan vistas. For, unless you rise before dawn and join the noisy convoys of tourist jeeps heading for Observatory Hill, these postcard views may be your only chance to see Khangchendzonga, India's tallest mountain. By day, the elusive Himalayas conceal themselves in thick creamy mists.

The Darjeeling Bose Institute, once the summer home of India's legendary scientist Sir Jagadis Chandra Bose (1858–1937), now accommodates the Centre for Astroparticle Physics and Space Science. Here, 4 kilometers above sea level, they are searching for the strange quark, an entity as elusive as fog-enshrouded Khangchendzonga.

In 2004, the house was preserved much as J. C. Bose had left it, its bookshelves bearing copies of *Transactions of the Bose Institute*. One could imagine J. C. Bose, seated on the green velvet sofa, in spirited conversation with his friend, the poet, novelist, short-story writer, composer, painter, and Nobel Laureate Rabindranath Tagore. Sister Nivedita may have joined them. Formerly Margaret Noble, the Irishwoman became a devotee of Swami Vivekananda, and devoted herself to women's education, social justice, and presenting Indian philosophy and culture to the West. A enthusiastic advocate of Bose's research, Nivedita exhorted him,

> *"...survey the vast accumulations which the 19th century has observed and collected, and demonstrate to the empirical, machine-worshipping, gold-seeking mind of the West that these also are one — appearing as many."*

The windows of Bose's study at the Darjeeling Institute stare out into the thick fog. A series of flat dark lines appears, cutting through the mist. Gradually the lines take shape, forming cones and crags. At first, it seems they are the mountains. Yet, they are mere foothills. The fog dissolves suddenly, and there it stands, Khangchendzonga soaring crisp and white. Bose must have seen it thus, countless times, as he worked at his desk.

On a wall next to the staircase is a framed copy of a letter Bose addressed to the Calcutta Municipal Gazette.

> *It is the resonance of things woven of memory that affects us deeply.* Bose writes, "*this city has been the place of my work for more than a third of a century. It is the watching of a roadside weed in Calcutta that turned the entire trend of my thought from the study of the inorganic to that of organized life.*"

3.3. Introduction

J. C. Bose wove a complex tapestry from the threads of physics, biology, botany, instrumentation, literature, education and philosophy. A significant figure in the Bengal Renaissance, Bose was close to Bengal's foremost artists and writers, including Rabindranath Tagore, and was himself an accomplished writer in Bengali.[104] From this multi-disciplinary milieu emerged Bose the scientist, in Tagore's words, "a poet in the world of facts",[51] a polymath informed by both Western and Eastern philosophies, who strove to uncover the themes with which disparate disciplines could be united. Unusually for his time, Bose succeeded in melding the specialist disciplines of physics and biology, and became one of the world's first biophysicists.

As a pioneer of semi-conductor technology, Bose had devised apparatus for generating and receiving microwaves (~1 cm to 5 mm radio waves, frequency 12–60 GHz), and invented numerous instruments now commonplace in microwave technology. Instead of remaining a physicist within this circumscribed field of expertise, Bose extended his specialised knowledge of physics and electromagnetic radiation into biological research, inventing unique, delicate instruments with which he measured bioelectric potentials, quantified small increments of growth, and recorded both subtle and spectacular movements of plants.

It has been said that there were two scientific Wests at this time — the first materialist, mechanistic, and colonial, whilst the second was vitalist and ecological[39] or organicist. The former would regard Bose as a controversial figure, whilst the latter would embrace his work. As Dasgupta writes,[41] by the late 1920s the world of plant researchers had split into "Bosephiles" and "Bosephobes".

As one of India's first modern scientists, living and working during the era of the British Raj, it is unsurprising that a legend has grown up in India of J. C. Bose as the "...lonely Indian David fighting a Goliathal British establishment ... the pitting of the colonized against the colonizer."[41] Nonetheless, Bose's research was so well-respected in some quarters that he had been knighted in 1917, and was elected a Fellow of the Royal Society in 1920.[104]

Late Victorian mechanistic materialist philosophies impelled reductionist agendas. The complex phenomena of life were to be reduced into simpler sub-components, and these were then to be explained in terms of the laws of physics. Scientists of the time were remarkably confident that the nature of matter and the laws of physics were so completely understood that life could be thus deconstructed and explained.

J. C. Bose on the other hand assumed an holistic position in his plant research. Rather than being merely passive automata, acted upon by the environment, he regarded all plants as active explorers of the world, responding to it through an underlying motif: *au fond* pulsatile schemata that coupled oscillations of electric potential with growth and movement, increase and decrease of turgor pressure, and contractility.

Bose maintained that plants and animals possess essentially the same fundamental physiological mechanisms. All plants co-ordinate their movements and responses to the environment through electrical signals and possess the equivalent of a well-developed nervous system. All plants have an electromechanical pulse, a kind of vegetable "heartbeat", and are capable of intelligent behavior, memory and learning.

Poorly received by the mechanistic materialist scientists of the day, such concepts have re-entered the mainstream literature. Today, the research field called "plant neurobiology", similarly aims to understand how plants perceive, remember and process their experiences, how they coordinate their responses to the world via integrated information networks that include molecular, chemical, and electrical signalling.[34] From this perspective, plants are neuronal, knowledge-accumulating systems.[13]

During the mid-19th century, industrialization in Germany had brought in its wake a move towards commodifying science, and this facilitated the emergence of hierarchically organized and bureaucratized institutes. In these, scientists operated as technologists, managers and entrepreneurs.[134] Bose swam against this current also, and persisted in regarding science as a vocation, or a calling. The Bose Institute in Kolkata would aim to advance and diffuse scientific knowledge, without taking patents, or seeking personal gain, "...without academic limitations ... henceforth to all races and cultures, to both men, and women alike, for all time coming."[29]

In this research atmosphere, "...the lines of physics, of physiology and of psychology converge and meet. And here will assemble those who would seek oneness amidst the manifold..."[29]

3.4. J. C. Bose — A Philosophy of Life

3.4.1. *From semi-conductors to sensitive plants*

A biography and review of the contributions of J. C. Bose to physics are included in this volume. Some aspects of Bose's life and physics research will be briefly considered, to shed light on his development as a biophysical scientist. Having studied physics, botany and physiology at Christ's College, the first Cambridge College to admit Indians,[104] Bose accepted in 1884 an appointment as Professor of Physics at Presidency College, Kolkata. Because experimental science had not yet emerged in India, his decision some years later to become an experimentalist was both courageous and groundbreaking. Lacking any established research facilities, Bose improvised and equipped a laboratory, and in 1894, he began the classic physical experiments that established him as a pioneer in the fields of semi-conductor and microwave technology.

In a prolific five years (1894–1899), Bose performed and published innovative research into the physics of electromagnetic waves. This period of his research is reviewed, both in this volume, and elsewhere.[21,22,50,85,99,108] Between 1985 and 1900, Bose published ten extraordinary papers in the *Proceedings of the Royal Society*, all of them communicated by Lord Rayleigh. Other papers were published in the *Philosophical Magazine* and *The Electrician*.[108] This work was much admired by distinguished physicists of the time, including Lord Rayleigh and J. J. Thompson.

Whilst the work of many of Bose's contemporaries now languishes forgotten in library vaults and archives, these hundred-year-old contributions

retain a contemporary edge. Concepts from his 1897 papers were recently employed in designing a 1.3 mm multibeam receiver, part of the 12 m radio telescope at the National Radio Astronomy Observatory in Tucson, Arizona.[50] At Lord Rayleigh's invitation, Bose had presented his radio work to the Royal Institution in 1897 (Fig. 19).

At the turn of the century, a scandal erupted over who had invented the "mercury coherer" (a semi-conducting diode) used by Marconi to receive the first trans-atlantic wireless signal in 1901. The "coherer with a telephone" could have been attributed to Castelli, or Solari, of the Italian Navy,[96] but Bondyopadhyay traces it to Bose's paper "On a self-recovering coherer and the study of the cohering action of different metals", published by the Royal Society in 1899. Bose had already given a spectacular demonstration of wireless signaling in 1895, with prominent members of the British Raj in attendance. A pulse of millimetre-length microwaves was transmitted from a sparking platinum ball, travelling 75 feet through three walls. After being focused through a lens, the pulse was received by a "coherer", setting off a relay, and dramatically firing a pistol and ringing a bell.

Bose's inclusive philosophy of research was at odds with the competitive, patent-driven efforts of some of his contemporaries, and he was adamant that scientific ideas should not be commercialized, patented, otherwise owned or exploited for personal gain. He appears to have been uninterested in competing for attention or claiming credit for the invention of the coherer, and evidently regarded the 1899 paper as a contribution to scientific knowledge upon which anyone could freely draw. Launching the Bose Institute in 1917, he said,

> *"...material activities have brought in the West their fruit, in accession of power and wealth. There has been a feverish rush even in the realm of science for exploiting applications of knowledge, not so often for saving as for destruction. In the absence of some power of restraint, civilization is trembling in an unstable poise on the brink of ruin."*
>
> *"Some complementary ideal there must be to save man from that mad rush, which must end in disaster ... far more potent than competition was mutual help and co-operation ... The ideal of giving, of enriching ... of self-renunciation in response to the highest call of humanity is the other and complementary ideal."*[29]

Bose's authorized biographer, Patrick Geddes noted[58]

> *"...(this) is the position of the old rishis of India ... whose best teaching was ever open to all willing to accept it."*

Consequently, only one of Bose's ingenious inventions was ever patented, and this was rather ironically at the insistence of Vivekananda, and Western supporters including Nivedita and Sara Bull.[21,22] The "electric eye", or detector for electrical disturbances, a remarkable invention inspired by the biological eye, was a galena crystal semiconductor diode detector, sensitive to microwave/millimetre and optical waves.[21,22,25]

In the aftermath of the first World War in Europe, many prominent Western intellectuals sought inspiration in Bose's humanist, pacifist and ethical philosophy of science. Amongst these was the Nobel Laureate Romain Rolland, an avowed pacifist who later wrote about Vivekananda and Gandhi, and wrote to Bose in 1927:

> *"...you have wrested from plants and stones, the key to their enigma ... you made us hear their incessant monologue, that perpetual stream of soul, which flows through all beings from the humblest to the to highest"* [cited in Ref. 89, p. 67].

Nobel Laureate, pacifist, and unabashed vitalist Henri Bergson remarked:

> *"...in Darwin's theory of natural selection ... conflict is the main theme; Jagadishchandra's research ... on the continuities and on the beauties of consistency in nature and in life"* [cited in Ref. 89, p. 68].

The great plant physiologist Gottlieb Haberlandt commented:

> *"...We saw that there is a sleep of plants in the true sense of the term ... In Professor Bose, there lives and moves that ancient Indian spirit, which sees in every living organism a perceptive being endowed with sensitiveness"* [cited in Ref. 89, p. 68].

The year 1900 marked not only the turn of the century but a turning point in Bose's research and life. He had established himself as a first-class, highly-original experimentalist and inventor, the first person to use

a semiconducting crystal to detect radio waves, the first to anticipate the *p*- and *n*-type semiconductors. His publication record was impressive: he was a distinguished experimentalist, a respected theoretician and teacher. The new century was to bring in its wake the first of a number of waves of controversy.

3.4.2. *Response in the living and the non-living*

Bose took the extraordinary conceptual step of applying techniques and delicate instrumentation developed in his work with semiconductors to various plant parts, including leafy stalks of horse chestnut, plane tree, celery, turnip, cauliflower and Eucharis lily, the storage roots of carrot and radish, the flower stalk of the Arum lily, and the fruit of the eggplant.[26]

A prodigious number of careful and ingenious experiments on plant parts led him to propound a radical theory. Parallels existed between the electrical characteristics of metals, including the (semi-conducting) coherers, and the electrical responses of animal and plant tissues to mechanical stimulation. There existed no sharp demarcation between the realms of the living and non-living.

Living animal and plant tissues exhibited, along with metals, a diminution of sensitivity after continuous stimulation, recovery after rest, a "staircase" or summation of electrical effects following mechanical stimulation, abolition of current flow after applying poisons, and reduced sensitivity at low temperature.

Bose wrote in 1900:

> *"...In studying the changes of conductivity produced in metallic particles by the stimulus of Hertzian radiation, I have often noticed that whereas feeble radiation produces one effect, strong radiation produces the opposite. Again, under the continuous action of electric radiation, I have frequently found recurrent reversals."*

Now he found that strong and feeble mechanical stimuli similarly produced bioelectrical responses of opposite polarity in the mechanically stimulated radish. The published record clearly shows what today would be called receptor potentials, small touch-induced transient depolarizations that precede an action potential. Furthermore, the form and polarity of these potentials depended on the condition and history of the plant and upon vitality — responsiveness disappeared when the tissue was killed with steam.

Bose reported his results at prestigious meetings and institutions, including the International Congress of Physics in Paris in 1900 (with the title "De la généralité des phénomènes moléculaires produits par l'electricité sur la matière inorganique et sur la matière vivante"); the Bradford Meeting of the British Association in 1900 (later published in *The Electrician* as "On the similarity of effect of electrical stimulus on inorganic and living substances"); the Friday evening discourse of the Royal Institution, May 1901 (with the title "Response of inorganic matter to stimulus"), and at the Royal Society in June 1901 (with the title "On electric response of inorganic substances. Preliminary notice."). Bose wrote:[26]

> *"...not the fact of response alone, but all those modifications in response which occur under various conditions, take place in plants and metals just as in animal tissues ... the wave of molecular disturbance in a living animal tissue under stimulus is accompanied by a wave of electrical disturbance; ... in certain types of tissue the stimulated is relatively positive to the less disturbed, while in others it is the reverse; ... this characteristic of exhibiting electrical response under stimulus is not confined to animal, but extends also to vegetable tissues. In these the same electrical variations as in nerve and muscle were obtained ... Passing to inorganic substances, and using similar experimental arrangements, we have found the same electrical responses evoked in metals under stimulus."*

These conclusions immediately established Bose as a controversial figure in certain Western scientific circles.

3.4.3. *On vegetable electricity: the making of a maverick*

In the audience for the 1901 lecture at the Royal Society were two prominent electrophysiologists, Sir John Burdon-Sanderson and Auguste Waller, who later became Bose's powerful professional enemies. It was in this lecture that Bose drew analogies between the semi-conducting electric characteristics of metals, and the changes in electric potentials he had measured following mechanical stimulation of plant tissues. He said,[27]

> *"...every plant, and even, the organ of every plant, is excitable and responds to stimulus by electric response."*

The professional conflicts that subsequently arose between Waller and Bose have been eloquently reconstructed and analyzed in Dasgupta's comprehensive article[41] and will not be dealt with in detail here. Suffice to say, Burdon-Sanderson objected to the use of the physiological word "response" in connection with metals, and insisted that ordinary plants did not have electrically mediated responses. Burdon-Sanderson, as the first to have measured action potentials in the Venus's Flytrap, was convinced that excitation was restricted to such strange and exceptional plants.

Waller made no comment, but in November 1901, he published his own paper, "Electrical response of vegetable protoplasm to mechanical excitation" in the *Journal of Physiology*, reporting, amongst other things, electropositive (depolarization) responses to mechanical stimulus in parts of ordinary plants (e.g. the vine-shoot). Thus, both Waller and Bose claimed priority for the discovery of "vegetable electricity", which undoubtedly contributed to the long-standing enmity between them. Bose's was the stronger claim to priority.[41] Indeed, Professors Vines and Howes of the Linnaean Society, who had read proofs of Bose's "vegetable electricity" manuscript (archived by the Royal Society five months before Waller's claim to priority), established a committee of inquiry of the Linnaean Society.[56] The inquiry granted Bose priority, and the Linnaean Society published his manuscript.

The roots of the professional conflict were established, and they were deeply established. Burdon-Sanderson later scathingly reviewed and recommended rejection of a *Mimosa* paper submitted by Bose to the *Proceedings of the Royal Society*. Paul Simons, describing the incident, writes,

> *"...Why he was so antagonistic amazes me. Was it professional jealousy because he himself had not investigated the Mimosa? Was it because Bose did not cite Burdon-Sanderson's paper on the Venus Flytrap?"*

Simons[119] writes that doubt had probably been cast on Bose's professional competence. Bose was controversial. He had said that there was no demarcation between life and non-life (had he said that metals are alive?), and furthermore the Victorian science establishment in England was not well-disposed towards mavericks.

Had Bose confined himself simply to electrophysiological records of plant responses to mechanical stimulus, *Response in the Living and Non-Living* would have stood alone today as a remarkable and

pioneering contribution to contemporary understanding of plant mechano-perception.

Had Bose included alongside his experiments with plants the reproductions of Waller's data on heart and muscle, drawing parallels with animal and plant responses, then *Response in the Living and Non-Living* would have been a controversial work, one that perhaps provoked some acrimonious debate, but it would have stood as the first articulation of the view that plants are neuronal organisms.

Instead, Bose's arguments about the responsiveness of metals, in analogy to animal or plant responsiveness, acted as a pivot that tipped *Response in the Living and the Non-Living* outside the boundaries of mainstream science.

Bose's insistence on the unity of the living and non-living arose from a deeply-held philosophical position,[41] Vedanta in inspiration, a monism that regarded the world as a single unified entity,[39] where mind and matter were aspects of the same thing. Indeed, his friend Tagore had hoped that Bose would validate Upanishad concepts of the unity of life, and, "*...through blurring the boundaries of life and non-life, their poetic and scientific visions could merge...*" (see Ref. 39, p. 198).

All science is philosophically informed. At that time, at least three philosophical movements, mechanistic materialism, vitalism, and organicism, were informing Western science and its experimental methodology.

3.4.4. *Nineteenth century mechanistic materialism and vitalism*

Burdon-Sanderson and Waller practiced a late-Victorian form of mechanistic materialistic science. Medicine was to be made rational or scientific by describing disease purely in terms of physiology, and physiology in turn would be ultimately reducible to the laws of physics. This was of course the 19th century physics that included Newton's mechanics, optics, thermodynamics, electricity and magnetism. The conceptual model of the body and of Nature that accompanies such a scientific rationale is that of a machine.

In scientific medicine, there would be no more discussion of subjective humors, constitution, emotion, or unmeasurable, unphysical aspects as causative agents in disease. The favored experimental method involved deconstructing complex biological forms and functions into their simplest parts, which could then be studied in isolation from one other. From this

ultimate physical level, one could then reconstruct the properties of the whole.[61] In such a conceptual framework, a living thing was, in essence, "nothing but" the sum of its parts.

This analytic-summative philosophy of science became prominent in the mid-19th century Germany as industrialization became widespread,[2] and it imbued the discipline of physiology with the idea that living bodies are machines — Descartes' *Bete Machine*.[47] Embedded in this philosophy was the assumption that cells, tissues and organisms respond passively to the physical and chemical features of their environments: "*...passive flotsam on a physico-chemical ocean...*"[2] Mechanistic materialism reached what was perhaps its apotheosis in behaviorist schools of psychology, associated particularly with B. F. Skinner, which sought to analyze the entirety of human experiences as coupled series of simple stimulus–response chains, employing pigeons and rats as simpler "models" of humans.

Burdon-Sanderson's 1873 and later papers on trap-closure in the Venus Flytrap are still cited today. Why then had this distinguished medical physiologist chosen a subject so far from his usual research focus, with its aim of "making medicine scientific" through animal experimentation.[98] Later assessments of Burdon-Sanderson's body of work[98] view his comparative electrophysiology as something of a *cul-de-sac* that detracted from his focus on infectious disease.

In fact, the idea of working on the Venus Flytrap was not Burdon-Sanderson's own. Charles Darwin had long been intrigued by the slow and subtle movements of plants. In 1880, he published *The Power of Movement in Plants* with his son Francis Darwin. They drew an analogy between the sensory and exploratory capacities of the root tip and the brains of "lower animals".

Darwin was interested in pursuing further analogies between the physiology and behavior of animals and plants. On 15th August 1873, he wrote to the eminent Burdon-Sanderson, suggesting that electrical changes might be associated with trap-closure in the Venus Flytrap. A month later, Darwin wrote back, pleased that the physiologist had been able to confirm the involvement of electrical activity (action potentials) in the spectacular process of trap-closure. Darwin continued a lively correspondence with Burdon-Sanderson about the digestive process in insectivorous plants like the Venus Flytrap. Was it like the process in an animal's stomach? Burdon-Sanderson was able to confirm that digestive enzymes within the trap did indeed act upon meat in analogy to a stomach.

However, in 1873, not long after publication of the Venus Flytrap work, this lively correspondence ceased, and the two began to exchange letters preoccupied with the activities of "anti-vivisectionists", vocal opponents of animal experimentation, and with ways of dealing with a looming Vivisection Bill that Burdon-Sanderson perceived as a threat to his work.

Both Burdon-Sanderson and Waller had encounters with "anti-vivisectionists", whom they regarded as unscientific impediments to advances in physiological research. It is even possible that Burdon-Sanderson's book, *Handbook for the Physiological Laboratory*, also published in 1873, contributed to the passing of the "Cruelty to Animals Act" in England in 1876. The Handbook described procedures for animal operations without outlining any policy for using anesthesia, and the Act made anesthesia mandatory.

Within the mechanistic materialist framework, a capacity to ignore the suffering of experimental animals in the name of scientific advances benefiting humankind was paradoxically sometimes viewed as a form of scientific heroism. One of the discipline's founders, Claude Bernard, had remarked[95]:

> *"...A physiologist is no ordinary man. He is a learned man, a man possessed and absorbed by a scientific idea. He does not hear the animal's cries of pain. He is blind to the blood that flows. He sees nothing but his idea, and organisms which conceal from him the secrets he is resolved to discover."*

In his evidence to the Royal Commission in 1875, Emmanuel Klein, a contributor to Burdon-Sanderson's Handbook, stated that he paid no attention to animal suffering — although some animal experiments were inevitably painful — and he never gave anesthetics except to keep the animal still, to stop it crying out, or to avoid being bitten. Such attitudes naturally generated anxieties in society at large, and these found expressive form in several novels of the time — Wilkie Collins' *Heart and Science*, a novel strongly critical of the vivisectors, and Bram Stoker's *Dracula*, which mentions Burdon-Sanderson by name.[95]

The intensity of Burdon-Sanderson and Waller's antagonism towards Bose becomes at least partly explicable against such a background. Not only did it seem that Bose was claiming an electrical "response" in metals, in analogy to those in animal and plant tissues, but that ordinary plants, like

animals, had nervous systems. One could even obviate the very need for animal experimentation by working with plants. As Bose wrote later[28]:

> *"...the complex mechanism of the animal machine that has long baffled us, need not remain inscrutable for all time, since the intricate problems of animal life would naturally find their solution in the simpler vegetable life*, and this would mean *very great advance in the sciences of general physiology, of agriculture, of medicine and even of psychology."*

Such views would clearly have been anathema to the two medical physiologists.

To Bose, the problem was more easily understood[29]:

> *"...I had unwittingly strayed into the domain of a new and unfamiliar caste system, and so offended its etiquette ... an unconscious theological bias was also present.... To the theological bias was added the misgivings about the inherent bend of the Indian mind towards mysticism and unchecked imagination.... Thus no conditions could have been more desperately hopeless than those which confronted me for the next twelve years."*

Mechanistic materialism and vitalism have often been posited as poles of a binary philosophic opposition, but this is an oversimplification.[2] Nonetheless, it is fair to say that 19th century mechanistic materialist research aimed to exorcise from biology the concepts of vitalism and "Naturphilosophie". Vitalism, which had formed the basis of experimental biology in the first half of the 19th century, had itself aimed to exorcise the concept of divine intervention from scientific discourse. Vitalists had proposed the existence of a non-material "life-force", an "entelechy", or *vis viva* that animated the physico-chemical constituents of living organisms.

From the time of its discovery, electromagnetic energy was associated by vitalists with the *vis viva*. Eighteenth century pioneers such as Stephen Hales suggested that nerves conducted the vital force in the form of "electrical powers".[17] Galvani's famous experiments with twitching frog's legs in 1791 at first seemed to confirm the electrical nature of the vital force. Muscles would contract when an electrical circuit was made between nerve, two dissimilar metals in series, and another part of the animal's body.[17,135] Galvani published his discovery of an "electric fluid" in 1791, with the title *De Viribus Electricitas in Motu Muscularis Commentarius*, or *Comments on Electrical Forces in Muscular Motion*.

A scientific dispute arose between Galvani, his nephew Aldini, and their compatriot, physicist Volta. It was no less acrimonious than that between Bose and Waller concerning "vegetable electricity".

Volta, skeptical, competitive, possibly jealous of Galvani's work and growing fame, doggedly argued that the electricity in the dancing frog-leg experiments was generated by the metallic interface in the circuit, and had nothing whatsoever to do with biology, or "vital forces". As a corollary of his sustained efforts to refute Galvani, Volta's discovered bimetallic electrical conduction and invented the Voltaic battery in 1880.[135] Galvani wrote:

> *"I am attacked by two opposite sects — the scientists and the know-nothings. Both laugh at me, calling me the 'frog's dancing master'. Yet I know that I have discovered one of the greatest forces in nature."*

Galvani has (unjustly) acquired a reputation as a scientist who accidentally made some interesting observations, but clung to a quasi-mystical idea of "animal electricity" because his limited imagination rendered him incapable of pursuing coherent research.[97] Galvani was actually a careful experimentalist and inspired theoretician. In later experiments, he proved that the frog's legs would twitch when no bimetallic interface was present, so long as the leg was touched with long sciatic nerves of the animal's exposed spinal cord.[135]

Galvani's explanation for animal electricity pre-dated Bernstein's later Membrane Theory of bioelectric potentials. Animal electricity, reasoned Galvani, was the result of accumulated positive and negative charges on the inner and outer surfaces of nerve and muscle, with water-filled pores facilitating current flow "...similar to the electrical circuit which develops in a Leyden jar," he wrote.[97] Galvani's nephew Aldini, who had so ferociously defended his retiring uncle, then took a turn at being portrayed as a character in a novel. His grisly experiments electrifying guillotined heads made him the model for Frankenstein, in Mary Shelley's novel *Frankenstein: A Modern Prometheus.*

Galvani fell upon hard times. His wife died, and he opposed Napoleon's takeover of Bologna, suffering political persecution as a result, losing his home, his position and his fortune. In contrast, Volta presented his battery to Napoleon, received a gold medal, and later became a successful politician. The controversy over the existence of animal electricity was resolved shortly before Galvani's death, when, in 1779, Humboldt proved the existence of both Galvani's "animal electricity" and Volta's "bimetallic electricity". Galvani and Volta were both partly right and partly wrong.[17]

3.4.5. *The mechanistic materialist position on animal electricity*

German mechanistic materialist philosophies had begun to shape the science of physiology in the mid-19th century, and a focal group, the New Physicalist School, worked on the nerve action potential. Including Du-Bois-Reymond and his student Bernstein, the New physicalists were determined to dispel "Naturphilosophie" and what they perceived to be the mists of vitalism, seeking a purely physico-chemical explanation for animal electricity.[134]

Following Nobili's 1858 invention of the galvanometer, an instrument that could detect the flow of electrical currents, Du-Bois-Reymond showed that stimulation of a nerve resulted in a propagated electrical disturbance (depolarization) that provoked muscle contraction. Du-Bois-Reymond's student Julius Bernstein took this discovery further, inventing the "rheotome" or "current slicer", a galvanometer with a timer and sampling device with which he produced the first true recordings of resting and action potentials, measuring their velocity at 25–30 ms^{-1}.[109]

In 1902, Bernstein formulated his Membrane Theory, incorporating Nernst's equations describing electrocatalytic theory, and Overton's concept of the lipid membrane. The Membrane Theory in essence described a cell as an electrolytic solution bounded by a selectively permeable membrane. Bernstein wrote[106]:

> *"...The electrical potential difference of the lesioned muscle is caused by the electrolytes, in particular by inorganic salts such as* K_2HPO_4 *already contained in the muscle fiber."*

It was not until 1949 that Hodgkin and Katz introduced Na^+ influx to the theory, and the concept of the Na^+/K^+ exchange pump became firmly established.

Bernstein's physico-chemical theory provided a satisfyingly mechanistic explanation of the action potential, and it spelled the end of the idea of "animal electricity" as a vital force. Such was the intellectual environment in which Burdon-Sanderson and Waller were immersed. By 1930, "...anyone who aspired to a career in the medical or biological sciences was well-advised to hesitate before publicly proposing that electromagnetic forces had any effect on living things, other than to produce shock or heating, or that such forces played any sort of functional role in living things."[17]

Ironically, as his life neared its end, Burdon-Sanderson expressed dissatisfaction with the purely physico-chemical theories he had spent his life developing. In a letter to his co-worker Florence Buchanan, Burdon-Sanderson remarked that the most accurate measurements of intensity, location and time relations of excitation still did not reveal the nature of the excitatory process. The link between excitation and response was,

> *"...something ... involved in the organisms for which the proper designation is organismal ... the organismal link or nexus is the essential part of the excitatory process ... the electrical machinulae are acted upon by the organismal stuff, not by their neighbors. Propagation is a vital process, not a physical one..."* [quoted in Ref. 65].

3.4.6. *J. C. Bose and western process philosophy*

Response in the Living and the Non-Living was published in the same year as Bernstein's Membrane theory, but its conclusions were very different. Instead of an ionic theory of electrical phenomena such as the action potential, Bose had proposed an all-embracing unification of the living and non-living through differentiated electromagnetic vibration (electrical pulsations or fluctuations), writing:

> *"...stimulus produces a certain excitatory change in living substances, and that the excitation produced sometimes expresses itself in a visible change of form, as seen in muscle; that in many other cases, however — as in nerve or retina — ... the disturbance produced by the stimulus exhibits itself in certain electrical changes ... whereas the mechanical mode of response is limited in its application, this electrical form is universal."*

> *"This irritability of the tissue, as shown in its capacity for response, electrical or mechanical, was found to depend on its physiological activity ... it could be converted from the responsive to an irresponsive state, either temporarily as by anesthetics, or permanently as by poisons ... when killed (the tissue) passes out of the state of responsiveness into that of irresponsiveness; and from a confusion of "dead" things with inanimate matter, it has been tacitly assumed that inorganic substances, like dead animal tissues, must necessarily be irresponsive, or incapable of being excited by stimulus — an assumption which has been shown to be gratuitous."*

Bose has been criticized for holding vitalist views,[89] but the conclusion of *Response in the Living and Non-Living* is actually highly critical of vitalism:

> *"...This 'unexplained conception of irritability became the starting-point', to quote the words of Vernon, 'of vitalism, which in its most complete form asserted a dualism of living and lifeless nature ... The vitalists soon,' as he goes on to say, 'laid aside, more or less completely, mechanical and chemical explanations of vital phenomena, and introduced, as an explanatory principle, an all-controlling unknown and inscrutable' force hypermécanique."*

> *"While chemical and physical forces are responsible for all phenomena in lifeless bodies, in living organisms this 'vital force' induces and rules all vital actions."*

> *"...From this position, with its assumption of the super-physical character of response, it is clear that on the discovery of similar effects amongst inorganic substances, the necessity of theoretically maintaining such dualism in Nature must immediately fall to the ground."*

Bose was neither a vitalist, nor a mechanistic materialist. His use of the physiological word "response" in relation to metal wires, and his claim that metals, like plant and animal tissues, responded to stimulus, suggests that his philosophical position, in Western terms, was closer to 'organicist' philosophies, and in particular to process philosophy.

3.4.7. *Whitehead's process philosophy*

The English mathematician, logician and philosopher Alfred North Whitehead spent ten years writing the *Principia Mathematica* with his student Bertrand Russell, and yet the two parted company philosophically. The essence of the conflict can be summed up simply. Russell argued that "life is matter-like", and Whitehead, that "matter is life-like".[19] Whitehead reasoned that the final concrete entities from which the world is made ("actual entities") are really "occasions of experience" — events or processes, rather than "things" or "substances".[1] Whitehead wrote[139]:

> *"...abandon Newtonian absolute time and space, and also particles of matter, substituting systems of events."*

In process philosophy, the concept of "an electron" expands to become a stream or collective of electronic entities, each lasting only briefly, each constituting an event, and where the summed events are the electron's life path.[1] Whitehead argued that mind had not emerged from matter that was initially mindless. Actual entities (or "occasions"), being fundamentally processes, have an experiential aspect. Even subatomic particles have some subjective experience, some degree of self-awareness. Mind is then implicit even at the level of fundamental particles.

The level of self-awareness relates to situational organization. We assume that the subjective aspects of electrons' situations is negligible in our terms. However, electrons within a living body differ from those outside it because of the complex organization of a living body, with, for example, electron transport chains as the basis of photosynthesis and respiration. In living things[139]:

> *"...coordination has been achieved that raises into prominence some functions inherent in ultimate occasions. For in lifeless matter, these functionings thwart each other, and average out so as to produce a negligible total effect. In living bodies, the coordination intervenes, and the average effect of these intimate functionings has to be taken into account."*

Aspects of Whiteheadian process philosophy are argued today. In the context of quantum physics, some physicists (e.g. see Ref. 121) regard "occasions of experience" as being akin to quantum events, and treat process philosophy as a theoretical framework for quantum theory. In neuroscience, process philosophy has been applied to notions of consciousness (e.g. Ref. 67).

In process philosophy, the difference between the living and the non-living becomes a matter of degree.

The concepts of "life" and "non-life", like that of "intelligence", are extremely difficult to define. Biological texts from the first half of the 20th century customarily began with an attempt at defining life, even if the task was impossible — for example, "Yes; life, if indefinable, is rhythmic".[122] Contemporary biological texts seem to avoid the question, except perhaps in exobiological circles.

One of the best-known attempts at a definition of life was contained in physicist Erwin Schrödinger's famous book, *What is Life*, published in 1943. Schrödinger began with the question[106]:

> *"...How can the events in space and time which take place within the spatial boundary of a living organism be accounted for by physics and chemistry?".*

Schrödinger focused on two aspects that characterize living systems. First, organisms feed upon "negative entropy" or order, drawing order in from their surrounds[106]:

> *"...the essential thing in metabolism is that the organism succeeds in freeing itself from all the entropy it cannot help producing while alive ... attracting as it were a stream of negative entropy upon itself, to compensate for the entropy increase it produces by living and thus to maintain itself on a stationary and fairly low entropy level ... maintains itself stationary at a high level of orderliness by continually sucking orderliness from its environment."*

Schrödinger devotes much of his book to a second aspect that characterizes life — the transmission of information (in the form of genetic material) into the future.

Put simply, life evolves, and life possesses memory.

Incorporating Whitehead's process philosophy into this statement, we could say that life is evolving mind-matter, and it possesses memory.

Bose had proposed that metals possess rudimentary elements of responsiveness, and that electromagnetic "pulsations" or oscillations unite the realms of the living and non-living. Living animal and vegetable tissues under stimulus produced waves of "electrical disturbance" that Bose claimed were also evoked in metals under stimulus.

Of course, today the widely accepted view is that bioelectric potentials, and phenomena including the action potential and mechano-perception, are explicable through ionic conduction processes involving ion channel proteins integral with cell membranes. Organisms do not contain wires, and metal-type electronic conduction plays no significant role in the development of cell electric potentials or excitability. The response-curves Bose obtained with metals would today be viewed as perhaps resulting from the breakdown and build-up of surface oxide layers, leading to changes in current flow.

However, the concept that electromagnetic oscillatory phenomena potentially provide evolving mind-matter with memory is perfectly compatible with contemporary process philosophy.

As physicist Henry Stapp writes,[119]

> *"...The evolutionary problem ... requires that systems that evolve by exploiting the causal efficacy of psychical realities associated with them must have some sort of memory capacity and the most rudimentary sort of efficacious dynamical*

> *memory probably resides in sustained oscillatory motions. This suggests to me that the physical correlates of the psychical realities will reside in the low frequency components of the coulomb part of the electromagnetic field. These are dominated by so-called coherent states, which are known to be essentially classical in nature and particularly robust. This would allow psychical realities in the sense considered here to be present in the simplest life-forms and to predate life."*

As for Bose's experiments with metal responsiveness, the following comment from Whitehead is perhaps apt:

> *"...In the real world it is more important that a proposition be interesting than that it be true. The importance of truth is that it adds to interest..."*
> [Whitehead, 1929, quoted in Ref. 19]

It remains to make one final comment on similarities Bose perceived between semi-conducting properties of metals and bioelectric potentials in living tissues. We can presume that Bose was very familiar with semi-conducting properties of certain metals, crystals, and compounds. As the first person to use a semi-conducting crystal to detect radio waves, he "....anticipated the existence of *p*-type and *n*-type semi-conductors".[50]

The idea that cells share some properties with semiconductors is not entirely far-fetched. In the 1940s, Nobel Prize winner Albert Szent-Gyorgi advanced the contentious idea that semi-conduction plays a role in conducting electricity along chains of proteins within cells.[123] Semiconductors are usually materials with highly ordered or crystalline structure, where the whole system shares the valence electrons. In *n*-type semi-conduction, the negative current is the consequence of atomic impurities, with fewer electrons than the other atoms, acting as "holes" that can be occupied by other electrons, leaving in turn further "holes" when electrons move. In *p*-type semi-conduction, the positive current results from movement of the electron "holes". Szent-Gyorgi reasoned that highly-ordered fibrous proteins, like those of the cytoskeleton, could similarly conduct electrons. A cell would theoretically become a single coherent electronic system, a sort of living integrated circuit.

The idea has been disputed and theoretically discredited, but some proteins do have semiconducting properties.[71,90] The notion that proteins can conduct electricity has in part formed the basis of molecular electronics.[71] The growth response of living bone to mechanical stress is based on the semi-conducting properties of bone.[16]

In summary, Bose's philosophy that animals and plants were not less than human, but part of a continuum of existence that included the inorganic, was ages-old in the East. In *Response in the Living and Non-Living*, Bose claimed to produce scientific evidence that any sharp demarcation between the realms of living and non-living was illusory.[29] Matter has life-like properties:

> *"...how can we draw a line of demarcation and say 'here the physical process ends and there the physiological begins?' No such barrier exists ... the responsive processes in life have been foreshadowed in non-life..."* and
>
> *"...At the source of both the inner and outer lives is the same Mahashakti who powers the living and the non-living, the atom and the universe"* and
>
> *"...The barrier which seemed to separate kindred phenomena was found to have vanished, the plant and the animal appearing as a multiform unity in a single ocean of being..."* [Bose cited in Ref. 39]
>
> *"...It was when I came upon the mute witness of these self-made records and perceived in them one phase of a pervading unity that bears within it all things — the mote that quivers in ripples of light, the teeming life upon the earth, the radiant sunlight that shines above us — it was then that I understood for the first time a little of that message proclaimed by my ancestors on the banks of the Ganges thirty centuries ago. They who see but one in all the changing manifoldness of this universe, unto them belongs Eternal Truth — to no-one else, unto no-one else!"* [Bose, 1901, Friday Discourse, Royal Institution, cited by Ref. 39]

3.4.8. *A phenomenology of plant mechano-perception*

In 2008, plant scientists accept, as did Bose, that the capacity for perceiving and responding to mechanical stimuli is not restricted to plants that make dramatic and obvious movements like the leaf-dropping *Mimosa* or the insect-trapping Venus's Flytrap. Plants, with their sessile habits, are fundamentally tactile organisms. As Bose had asserted over a hundred years ago, mechano-perception underlies many subtleties of plant behavior, including responses to gravity, temperature, osmolarity, and turgor-controlled growth and development.[8,9]

We are now comfortable with the evidence that plant cells transduce mechanical stimuli into electrical code. It is difficult to imagine how remarkable such transduction must have seemed in 1900. In *Response in the Living and Non-Living*, Bose had laid the foundations for a phenomenology of plant mechano-perception, and delineated characteristics of excitation that are now amongst the general *corpus* of plant electrophysiological lore. Importantly, Bose had identified the electrical depolarizations induced by mechanical stimuli (such as torsion and tapping) that we now call receptor and action potentials. "*...The swaying of a tree in the wind would thus appear to give rise to a radial EM*", he observed.

In the mechanically stimulated turnip, Bose demonstrated "summation" of electrical responses, showing that a single stimulus producing no measurable electrical response led to a large depolarization (probably an action potential) after a thirty-fold repetition. The "all-or-none" property of mechanically induced action potentials was, Bose noted, similar to the responses of animal tissue[26]:

> "*...During the gradual increase of the stimulus from a low value there would be apparently no response. But when a critical value was reached, a maximum response would suddenly occur, and would not be exceeded when the stimulus was further increased. Here we have a parallel to what is known in animal physiology as the "all or none" principle. With the cardiac muscle ... there is a certain minimal intensity which is effective in producing response, but further increase of stimulus produces no increase in response...*"

Fatiguing, or diminution of the electrical depolarization measured by Bose in celery, radish and cauliflower after repeated stimulus, is equivalent to our current understanding of the "refractory period" that follows an action potential, during which stimulus will not produce another action potential. The temperature-dependence of action potentials demonstrated by Bose is now well-known (e.g. see Ref. 20).

That electrical responses are arrested when tissues are killed with steam, or treated with anesthetics, is also well-known today. Indeed, anesthetics nearly eliminate the leaf-dropping tactile response in *Mimosa pudica*.[83] The mode of action of anesthetics is still not understood. Various authors suggest that in plants the volatile and local anesthetics may inhibit Ca^{2+}-sensitive ion channels,[5] the actin cytoskeleton,[57] induce phase changes in cell membranes[93] and impact on morphogenesis.[105]

The specific means by which mechanical stimuli are transduced into electrical form remains unknown today. Current opinion states that deformation of the cell membrane, either directly, or indirectly, via transmembrane protein tethers coupled to the cytoskeleton and the cell wall,[8] activates mechanosensory Ca^{2+} ion channels. Force perception then translates into activation of mechanosensory Ca^{2+} ion channels, which are differently modulated, accounting for a multiplicity of responses. Mechano-perception and response depends on Ca^{2+}-dependent second messenger systems.[66,75] In Trewavas' model of plant learning,[126,127] each kind of mechanical stimulus must elicit a unique Ca^{2+} signal.

The Ca^{2+} released stimulates Ca^{2+}-activated Cl^- channels,[72] producing a Cl^- efflux,[115] which constitutes an electrical signal, the small depolarization called the receptor potential. The receptor potential increases in amplitude and/or duration incrementally with increasing magnitude of stimulus,[72,74,115] until a critical threshold voltage initiates an action potential (reviewed in Ref. 18). A progressive increase in the magnitude of depolarizations with repeated stimuli, the "staircase effect" described by Bose, resembles the summation of receptor potentials described later by Kishimoto.[74] Like Kishimoto, Bose noted that "summation" did not occur if stimuli were separated by wide time intervals.

In contrast to the receptor potential, an action potential is a dramatic depolarization, and elevation of cytoplasmic Ca^{2+} is sufficient to halt cytoplasmic streaming. So drastic is the action potential that it can be regarded as a phase transition in a system poised far from equilibrium. The elevated Ca^{2+} activates Cl^- efflux via Ca^{2+}-activated Cl^- channels, further depolarizing the cell, and thereby activating outwardly-directed voltage-dependent K^+ channels (reviewed in Ref. 18). Action potentials have a characteristic form and critical voltage threshold for initiation, and unlike receptor potentials, propagate from cell-to-cell.[18] The result is an efflux of Cl^- and K^+,[18,138] water efflux and transient turgor reduction[140] and cell contraction.[92]

The action potential motif (elevated cytoplasmic Ca^{2+}, efflux of Cl^- and K^+, and turgor loss and contractility), has been elaborated by plants into turgor-based osmotic machinery that enables a wide repertoire of behaviors.[69]

As Bose reported, the electrical response to mechanical stimulus depended on the condition of the plant tissue and its history with respect to previous stimulations. The latter is of course highly significant in any consideration of plants as intelligent organisms, and is a focus of the emerging field of plant neurobiology.

3.5. Plant Neurobiology Today

3.5.1. *Towards plant neurobiology*

Nearly a hundred years after Bose's research, the critical role of electrical signaling in plants was validated convincingly by Wildon *et al.*,[139] who demonstrated that a flame wound brought about activation of proteinase inhibitor genes in distant tissues — not by a chemical signal, but electrically. In this case, the actual electrical signal was a slow-wave potential or variation potential, an electrical variation in living cells due to a hydraulic surge rather than an action potential.[44] A similar flame-induced electrical signal transiently halts photosynthesis in *Mimosa pudica*.[77]

Most, and perhaps all plant cells are excitable, responding to stimuli such as heat, cold, wounding, touch, and changes in extracellular osmotic pressure with electrical signals. Signals may be restricted to a single cell (receptor potentials), transmitted over relatively short distances (variation or slow-wave potentials) or transmitted over long distances (action potentials). At the time of Bose's death in 1937, and afterwards, electrical signaling in plants had become a marginalized topic of limited interest.

A widespread assumption was made that plants, making their slow and subtle movements, manifestly lacking eyes, ears, noses and obvious brains, being simple automata passively responding to the vagaries of the environment, have no "need" for a nervous system and therefore do not possess one. Went's discovery in 1928 of the growth regulator indole-acetic acid (auxin) focused the attention of plant scientists on chemical signaling, which was thought to occur predominantly by diffusion, and therefore matched the slowness and passivity expected of a regulator of plant responses.

By the 1970s and 1980s, many plant electrophysiologists had made a strong case that action potentials should be regarded as multi-functional electrical signals (e.g. Refs. 42, 43, 98 and 138 (reviewed)), employed by plants in actively constructing their responses to the world. Reluctance to accept such a coordinating role for electrical signals, particularly in the USA, has been attributed to institutional nationalism, racism, sexism, and the parapsychological interpretation of plant behavior in popular books.[111,114,138]

According to Davies,[44] Tompkins' and Bird's best-seller, *The Secret Life of Plants*, published in 1973, made research into plant electrical signals "...untouchable in the eyes and minds of funding agencies". Unusually for a popular book, it was critiqued in *Nature* by Galston and Slayman,[56] who viewed the chapter on Bose's research favorably, but were strongly critical of the work of a discredited lie-detector expert. He had, they stated, fostered

unscientific beliefs about emotional communication between plants and humans.

The research of Wildon *et al.*[139] contributed to the shift in attitude of plant scientists that began in the 1990s, from a viewpoint espousing that plants use predominantly chemical signals to one emphasising electrical signals.[100]

Plant neurobiology[12,15,34] is a relatively new and somewhat controversial addition to the discipline of plant sciences. It aims to provide both a forum and a context for investigating the means by which plants perceive features of the world, transduce this information into electrical, hydraulic and chemical signals, and subsequently respond physiologically, morphologically, and behaviorally.

Rather than the traditional emphasis on differences between animals and plants, plant neurobiology is inclusive, focusing on similarities. Indisputably, animals and plants share major biochemical pathways, some neurotransmitters (including glutamate receptor-like genes), reproduce by similar fusion of gametes, develop immunity, and employ the same molecules and pathways to drive circadian/chronobiological rhythms.[12]

Plant neurobiology goes further still, asserting that the complexity of plants, whose capacities include making integrated responses to the environment, decision-making (e.g. the onset of dormancy or flowering), social learning, behavioral inheritance, and employing complex plant–plant, plant–insect and plant–animal communications, implies a far more sophisticated sensory perception than has hitherto been acknowledged.[13]

3.5.2. *Plant intelligence and the capacity for learning*

In his series of closely-reasoned, comprehensive and thoughtful reviews, Trewavas[128–131] shows us how biased is the usual concept of intelligence, where behavior is associated exclusively with the rapid movements made by animals. Applying the definition of intelligence from D. Stenhouse ("adaptively variable behavior during the lifetime of an individual"), Trewavas gives numerous examples of intelligent behavior involving growth and development in plants. These include roots navigating the maze of the soil, constructing a perspective of local space and adjusting growth patterns accordingly. Furthermore, plants actively forage, using strategies similar to those used by foraging animals. Plants can learn through trial and error, which requires having goals, assessing and modifying growth behavior. A kind of memory enables plants to anticipate difficulties, and to grow around them. Plant behavior is intentional.

Trewavas underlines the similarities between social insect colonies and plants. Both, he says, "*...gather information, evaluate, deliberate, form a consensus, make choices and implement decisions* ...", and this at a pace closer to that we expect from plants, rather than animals. Trewavas[129,130] draws a powerful and profound analogy between the intelligence of plants and the swarm intelligence of a bee colony. Bee researcher Thomas Seeley has long argued that hives are cognitive, "a colony of mind".[107,129,130] A bee colony is a cognitive entity that collects up-to-date information about the world, assesses this in light of its own internal state, thereby performing simple reasoning, and then goes on to make decisions promoting its own well-being in relation to the world.[107] The argument that only animals with brains can be intelligent is a form of brain chauvinism, Trewavas argues, and it endows animal nerves with a kind of vitalist quality.

Stomatal dynamics of leaves demonstrate a capacity for emergent, distributed computation that enables gas exchange to be optimized.[94] Even if one argues that plants have neither neuronal equivalents nor the capacity for learning, it is clear that memory (regarded as an ability to store and recall information) operates in *Bidens* seedlings.[121,122]

How is it possible for plants, which lack an obvious brain and the capacity for rapid movement, to foresee, remember, plan and respond? The current view is that electrical signaling, involving calcium release, underlies plant responsiveness, intelligence and memory.[23] Since calcium is either an agonist or antagonist of all plant growth regulators, including auxin,[52] this form of signaling is likely to be electro-chemical, as occurs in animals.

Recalling Ashby's Law of Requisite Variety, how can a simple divalent ion control processes that are far more complex? Trewavas[126,127] and Bose and Karmekar[23] propose a neural net concept of Ca^{2+} signaling as the basis of plant learning and intelligence. Electrical signaling systems (e.g. action potentials) that release calcium confer on plants the potential for computation, learning and memory. Changes in cytoplasmic Ca^{2+} are the basis of the intelligent system, not through Ca^{2+} diffusion, but through propagated waves of Ca^{2+} release. Plant cells potentially compute, remember and learn, through a Ca^{2+}-based neural net system.[23,126,127]

Calcium channels, located in plasma membrane, vacuolar and endoplasmic reticulum membranes, are envisaged as a network. Signals initiate the IP_3 cascade and Ca^{2+} channels open only when both IP_3 and Ca^{2+} bind. The released Ca^{2+} opens further channels, in a "Mexican wave", and can associate with Ca^{2+}-binding proteins. The Ca^{2+} waves are spatially structured, and the IP_3-sensitive channels make for a "coincidence counter".

Only specific directions are propagated whilst others are inhibited. Stimulus induces Ca^{2+} oscillations in plant cells.[81] Calcium oscillations reflect co-operative integration of the behavior of many IP_3-sensitive channels, and each Ca^{2+} channel or cluster of channels is the equivalent of a node in a neural network.

Each is a "switch" which can direct the flow of information, block or pass signals that arrive at the same time, and behave as an AND/OR logic gate. Trewavas argues that this Ca^{2+}-based neural net is a means for computing, remembering and learning that is unique to plants. It accelerates information transfer and it can be reinforced. Repeated signals make the path more sensitive whilst too many signals inhibit it. A similar Ca^{2+} signal can have different effects in different cells, which can remember previous experience, and know where, and what, they are.

3.5.3. *Root apex as the "plant brain"*

In plant neurobiological terms, plants as it were stand upon their heads. The root apex is regarded as the location of plant command centers, or the "plant brain", whilst the shoot apex, with its respiratory and reproductive organs (leaves and flowers) is regarded as the posterior pole of the body. Complex social interactions between plants, plants and fungi and plants and bacteria, are mediated primarily through the roots.[7,10]

This idea is not new. Charles and Francis Darwin had stated in 1880 that the "plant brain" was seated in the anterior end of the body, although they probably meant this purely as a metaphor. Of course, no-one is saying today that there are mini-human-like brains in the root system of a plant.

Ironically, the plant growth regulator auxin (indole-acetic acid) that dominated the field of plant chemical signaling, is now regarded as being a plant neurotransmitter. Polar auxin transport is thought by some researchers (e.g. Ref. 11) to be brought about by calcium-sensitive vesicle trafficking, via proton gradients generated by vacuolar/vesicular ATP-ases. According to these authors, polar auxin transport has much in common with synaptic signal transmission in excitable animal tissues, and plants show neuronal-like features in that the end-poles of elongating cells resemble chemical synapses. Thus, auxin is thought to be secreted from cell-to-cell, neurotransmitter-like, via vesicle trafficking. The end-to-end polarities of root apical cells, the enrichment of the end-poles with actin, and the cell-to-cell communication channels (plasmodesmata) at end pole walls linking adjoining cells, constitute

the synapse-enriched "transition zone" of the root. It has been suggested that the synapses in this region confer on the root apex the properties of a "brain", or command center, where incoming sensory signals are processed.[10,15]

3.5.4. *The vascular tissues, phloem and xylem, as plant neurons*

The phloem tissue can be regarded as a "supracellular axon-like channel" connecting the two poles of the plant body, the root and shoot.[12] Phloem transmits action potentials from leaf to leaf, root to leaf,[15] and also transports large RNA molecules. On the other hand, the non-living xylem elements are surrounded by living xylem parenchyma cells, and transmit hydraulic signals, such as the variation potential or slow-wave potential. Variation or slow-wave potentials are initiated by more drastic wounds (e.g. flame wounds) than action potentials.

The calcium-based plant action potential, described in Sec. 8, is comparable to the calcium-wave based action potentials of animal heart cells, but differs substantially from the animal nerve-action potential, which is driven by the Na^+/K^+ exchange pump.[45] Briefly recapping our current understanding of the plant action potential, it is measured as a substantial depolarization, the result of an inward flux of Ca^{2+} ions, which activates Cl^- efflux via Ca^{2+}-activated Cl^- channels, depolarizing the cell to a voltage threshold that activates outwardly directed K^+ channels and K^+ efflux. The traveling action potential wave involves influx of Ca^{2+}, efflux of Cl^- and K^+, cessation of cytoplasmic streaming, temporary contraction of cells, efflux of water, and transient turgor reduction.

The plant action potential has been assumed to be quite slow — those measured by Burdon-Sanderson scarcely proceeding more rapidly than diffusion. However, some researchers argue that this slowness is due to slow sampling speeds and aliasing errors in measurement. Volkov maintains that under different circumstances, the plant action potential wave travels at faster rates, in the range of cm s^{-1} (with insect predation the stimulus) to m s^{-1} in the presence of certain herbicides (e.g. PCP, or 2–4, dinitrophenol).[136] The latter, m s^{-1}, rate is comparable with the rate of animal action potential propagation.

It also seems clear that imposition of stress leads to production of electrical signals that can affect auxin production and bring about morphological responses.[14]

3.5.5. *Auxin as a plant neurotransmitter*

Many of the neurochemicals employed by animals are also present in plants, one prominent example being acetylcholine. Auxin, as an indoleamine, is chemically similar to well-known neurotransmitters melatonin and serotonin, both of which are found in large quantities in some plants — in particular, the medicinal plant St. John's Wort (*Hypericum perforatum*), which is used to treat depression in humans.[88]

Auxin induces the formation of new vascular strands ("nerves" — see below) and new root apices, whose transition zone is proposed to be the location of "command centers" or "brains". The polar transport of auxin across putative plant synapses suggests to plant neurobiologists that auxin should be regarded as a widespread plant neurotransmitter.

The polar transport of auxin is well-known: auxin is synthesized and transported away from the shoot apices and young leaves, whereupon it moves downwards, towards the root tip, and into the root cap (becoming involved in the gravi-response system). Some auxin is then subsequently redirected back from the root cap, moving via epidermal cells to the root transition zone. Thus auxin moves back from the root tip and root cap (which together comprise the plant brain, where sensory perception occurs) to the transition zone, a region where a response (e.g. gravitropism) is initiated.

According to Barlow,[14] this resembles efferent nervous activity in animals, where nervous impulses are directed away from the central nervous system (or brain) and towards a region of response — muscles or the transition zone. Conversely, the movement of auxin from leaves and shoots down towards the root tip resembles afferent nervous activity, which in animals directs impulses away from peripheral sensorial zones, conveying them towards the central nervous system and the brain.

3.5.6. *Three kinds of neural pathways*

In summary, plant neurobiology so far admits the existence of three kinds of neural pathways in plants. First, there is a pathway comprising phloem sieve tubes and their companion cells (reviewed in Ref. 45), through which action potentials are transmitted. Second, is the pathway comprising (non-living) xylem elements and their accompanying living xylem parenchyma, through which travel the variation (slow-wave) potentials — hydrostatic signals or pressure waves, inducing depolarizations of living parenchyma cells, and

which may involve the proton pump activity of living xylem cells. Slow-wave potentials are induced by more severe damage (flame wounds, etc.). Finally, as postulated by Baluska *et al.*,[11] there is the "plant brain", the transition zone of roots where actin-enriched fields of plasmodesmata at the end-poles of cells are regarded as synaptic connections.

3.5.7. *Sophisticated plant behaviors and communication*

In recent years, an increasing number of publications has attested to the complex social lives of plants. Even if the claim that plants have the equivalent of a well-developed nervous system is not accepted, it is nonetheless clear that plants anticipate the future, via perceptions of environmental cues, and possess memory — changing their behaviors on the basis of previous experience or experiences of their parents — and furthermore communicate with other plants, animals and fungi, emitting volatile chemicals that cause other organisms to behave in predictable ways (reviewed in Ref. 73).

For example, pine trees on whose needles the pine sawfly has laid its eggs emit volatile chemicals, a "cry for help" that entices parasitoid wasps, which then use the sawfly eggs to incubate their young.[68] When the lima-bean is attacked by aphids, it produces extra nectar, which attracts ants that then compete with the attackers.[76] Then, there is the recent and clear demonstration of kin recognition. Resource allocation to the roots of sea rocket plants increased when strangers were grown together in a pot, but not when siblings were grown together, and the roots provide cues for this kin recognition.[48] As a final example, the parasite dodder (*Cuscuta pentagona*) is clearly able to use volatile cues to locate, assess and select its prey, preferring tomatoes over wheat.[102]

3.5.8. *Living systems theory*

The use of terms such as "plant nervous system", "plant brain", "plant synapses", "plant intelligence" by plant neurobiologists has provoked some misunderstanding and controversy.[3] For this reason, Barlow[15] proposes adopting Living Systems Theory as a means for reconciling neural homoplasies between plants and animals. According to Living Systems Theory, each level of biological organization (e.g. cell, tissue, organ) is supported by a set of critical subsystems, which repeat at each level, building a "self-similar organizational hierarchy".[15] The subsystems and the information they contain together assemble a particular level of biological organization.

At each of these levels, the tasks of the subsystem is the same, but the elements that make up the subsystem and the means by which the tasks are accomplished are different, becoming more complex the higher the organizational level. Most of the twenty information processing subsystems are appropriate to plants, and at the organism level, the "channel and net" subsystem, with its criterion of transmitting electrical signals (action potentials) throughout the body, is appropriate to plant phloem tissues and animal nervous tissues.

3.6. J. C. Bose and the Roots of Plant Neurobiology

Bose continued to regard plants as intermediates in a continuum that extended between animals and the non-living materials to which he had devoted the first part of his career. Until his death in 1937, he persisted with the research into plant responsiveness that he had begun in 1900, performing hundreds of elegant and ingenious experiments, purpose-building an extraordinary ensemble of unique and delicate instruments. A prodigious output included books, research papers and essays.

Of this vast oeuvre, I will consider here only the books *Researches into the Irritability of Plants* (1913), *The Ascent of Sap* (1923), *The Nervous Mechanisms of Plants* (1926), as well as some selected papers. Bose's contribution to photosynthesis research has been reviewed elsewhere.[87]

In the works reviewed here, we will discover many of the antecedents of current plant neurobiology. The books form a self-referential, extended, and nonlinear narrative, baroque in their conceptual spread.

Cutting against the grain of the times, whose consensus held that plants are passive automata simply acted upon as windmills are by random environmental input, Bose advanced a view of plants as active and exploratory organisms, capable of learning from experience and modifying their behavior accordingly. Integral to this form of plant intelligence was a well-developed nervous system. Bose was the first person to use the term "plant nerve", and he used it confidently, locating the nervous route for long-distance electrical signaling in the vascular tissue, specifically the phloem.

As Trewavas has pointed out, plant behavior involves active phenotypic changes rather than the movements made by animals, although it is the latter that we have come to exclusively associate with intelligence. Difficult

though "intelligence" may be to define, few would disagree that intelligence implies the capacity to sense changes in the environment (information), to process, integrate and evaluate sensory perceptions, and finally to make decisions regarding a course of action/enactment of behavior.

Bose sought to research three such aspects of plant responsiveness including:

(i) contractility (movement following a stimulus),
(ii) conductivity (transmission of electrical excitation) and
(iii) rhythmicity (movements taking place automatically, analogous to a heartbeat) (see Ref. 27, p. 202).

He carefully selected experimental plants in order to compare and contrast these kinds of behaviours. Touch-sensitive species (including *Mimosa pudica*) responded to mechanical stimulus with electrical excitation and collapse (contraction) of their leaves. Other experimental plants (including the Indian telegraph plant *Desmodium*) made spontaneous rhythmic movements. Finally, Bose looked for rhythmic, contractile and excitation phenomena manifested by "ordinary" plants (including trees such as *Ficus*, *Nauclea*, the mango; monocotyledons such as the banana (*Musa*), palms; and *Chrysanthemum*), which did not make obvious rapid movements.

As a result of his research, Bose was able to unify many disparate areas of plant physiological research, proving that:

> "*...unity of physiological mechanism in all life. For we find, in the plant and in the animal, similar contractile movement in response to stimulus, similar cell-to-cell propagation of pulsatile movement, similar circulation of fluid by pumping action, a similar nervous mechanism for the transmission of excitation, and similar reflex movements at the distant effectors*" [see Ref. 31, p. 271].

All plants, Bose concluded, actively explore and respond to their worlds through a fundamental, pulsatile, motif in which oscillations of electric potential are coupled with oscillations of turgor pressure, contractility, and growth.

I will examine four major tenets of Bose's theory of plant behavior. How did these establish, a century ago, some of the fundamentals of contemporary plant neurobiology?

3.6.1. *All plants utilise a phloem-based nervous system to co-ordinate their responses to the perceived world*

Whether they be "sensitive plants" like the *Mimosa*, or less dramatically responsive, like the banana or *Nauclea*[27]:

> *"...the characteristics of the transmitted impulse as ascertained from the mechanical response of motile, sensitive plants find an exact parallel in the electric response of ordinary non-motile plants. They are in fact common to all plants..."*

The sensitive plant *Mimosa pudica* ("touch-me-not") folds its paired leaflets or drops the entire leaf when touched. Shaking the plant causes almost all the leaves to fall and all the leaflets to close. Clearly the plant was a tempting subject for studying plant movements in response to stimulation. Bose performed numerous experiments with *Mimosa*, only some of which are discussed here.

How could one simultaneously measure leaf movements and propagation of electrical signals? Bose designed an extraordinary instrument, the Resonant Recorder (Figs. 20–23), a delicate device with frictionless jeweled bearings, and a fine lightweight aluminium lever connected to the leaf, as well as a vertical lever (writer) that recorded the response on a moving smoked glass plate, operated by a clockwork mechanism. Friction of the writer against the smoked glass plate was avoided by having the writer make intermittent contacts with the moving plate [Ref. 32, p. 55; Ref. 27, Chap. 2), by passing periodic currents of exactly the same frequency through an electromagnet. Bose noted that the form and timing of stimulated leaf movements could thereby be recorded with extraordinary precision (~$1/100^{th}$ of a second intervals) — and "the record is thus its own chronogram" [Ref. 27, p. 22].

The motor organ in *Mimosa* is the pulvinus. Bose proved that excitation was induced by touch, sudden temperature change, by initiation or cessation of a constant current, and by induction shock. Importantly, an electrical stimulus could substitute for a mechanical (touch) stimulus.[27] The collapse of the leaves following stimulation was due to an electrically mediated loss of turgor pressure and cellular contraction in the pulvinus, whereas restoration of the leaflets erect position implied increase of turgor pressure and cellular expansion.

An extraordinary paper published in the *Proceedings of the Royal Society*[33] provided both detailed anatomical and electrophysiological proofs that

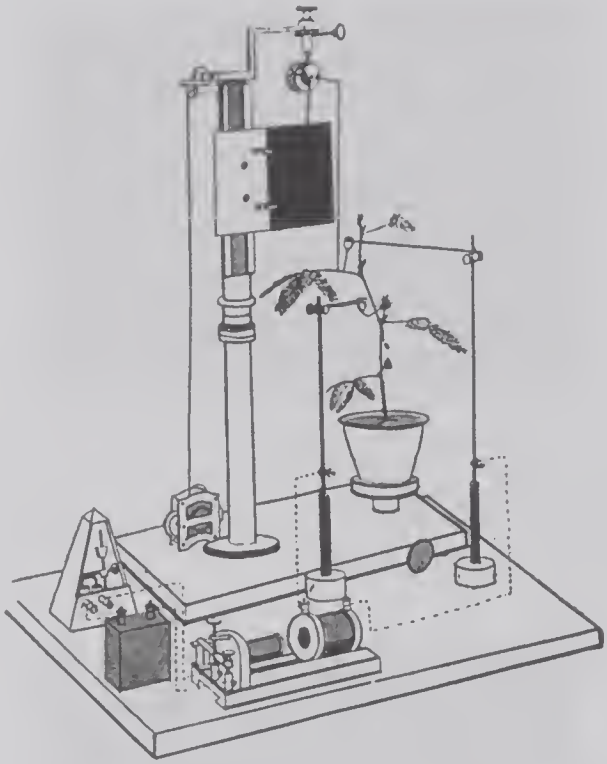

Fig. 20. The Resonant Recorder (reproduced from Ref. 27, Fig. 4). This device had "frictionless" jewelled bearings, a fine lightweight horizontal lever connected to the pulvinus or leaf, and a vertical lever for writing the response on a smoked glass plate, which moved at a uniform rate using a clockwork mechanism. In this configuration, the duration of an "induction shock" applied to *Mimosa* was determined by a metronome, which completed the electric circuit. The illustration shows a *Mimosa* plant ready for measurement of leaf movements.

electrical signals (resembling action potentials) controlled the leaf movements. The excitation was bipolar, moving both with and against the direction of the transpiration stream.

Bose and Das[33] provided unequivocal evidence that the phloem tissue was the functional equivalent of the plant nerve, and concluded that the *Mimosa* nervous system is complex, with both sensory and motor components. Electrical propagation depended on living cells.

This conclusion was made possible through use of another delicate instrument, the Electric Probe (Figs. 24–27), an early intracellular microelectrode, whose tip was in circuit with a sensitive galvanometer and could be driven into tissue in 0.1 mm increments. Different intensities of electrical

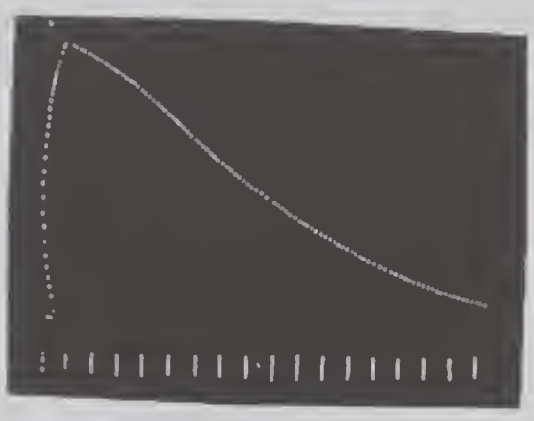

Fig. 21. The record shows the leaf-dropping response in *Mimosa* made with the Resonant Recorder (reproduced from Ref. 27, Fig. 14). Dots are at 1/10 s intervals during the "contractile" or leaf-dropping phase and at 10 s intervals during recovery. Vertical marks, indicate 1 min intervals.

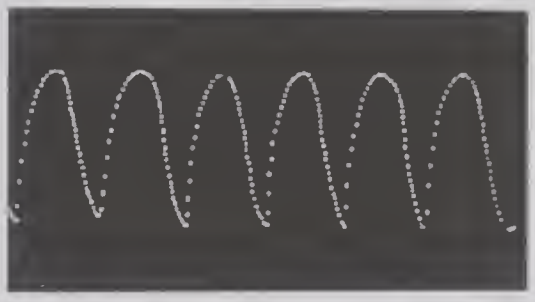

Fig. 22. The rhythmic gyrations of the leaflets of the telegraph plant *Desmodium* (reproduced from Ref. 27, Fig. 145). Individual dots are 2 s apart. This leaf was measured in summer and the whole period is about a minute, although in winter this increased to 4 or 5 minutes.

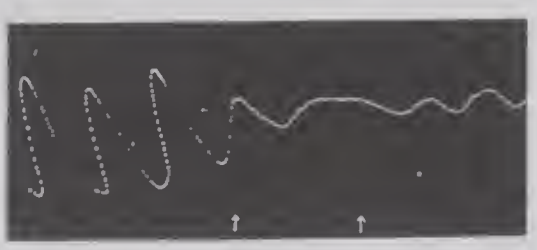

Fig. 23. Arrest of spontaneous movements in *Desmodium* by a cut applied at the first arrow. The pulsatile movement was revived by an electric shock at the second arrow. An electrical stimulus could be substituted for a mechanical one. (Reproduced from Ref. 27, Fig. 145)

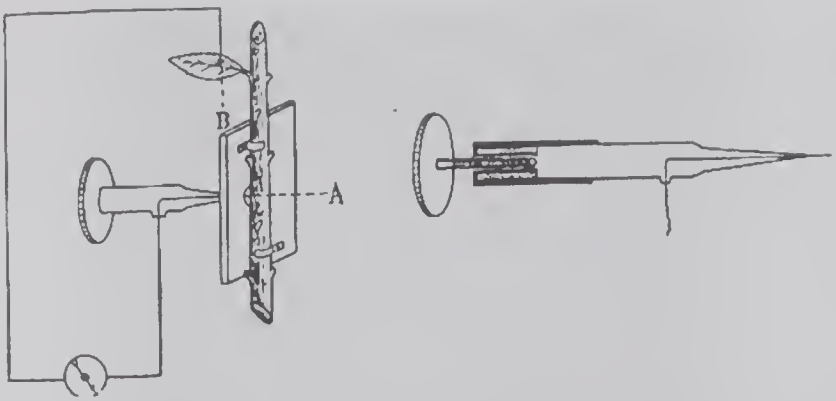

Fig. 24. The Electric Probe (reproduced from Ref. 31, Fig. 75). The tip of the probe was in circuit with either a sensitive or Einthoven galvanometer, and the device could be driven, by small (0.1 mm) increments into the tissue by turning the screw. Bose achieved remarkable precision of measurement — a deflection of 1 mm PD between electrodes was equivalent to a 1 mV deflection of the galvanometer. In some cases, he measured potentials as small as 0.1 mV. The tip of the probe enters at A, and a reference contact is made with a distant or dead leaf. The micrometric screw enables the probe to be gradually introduced.

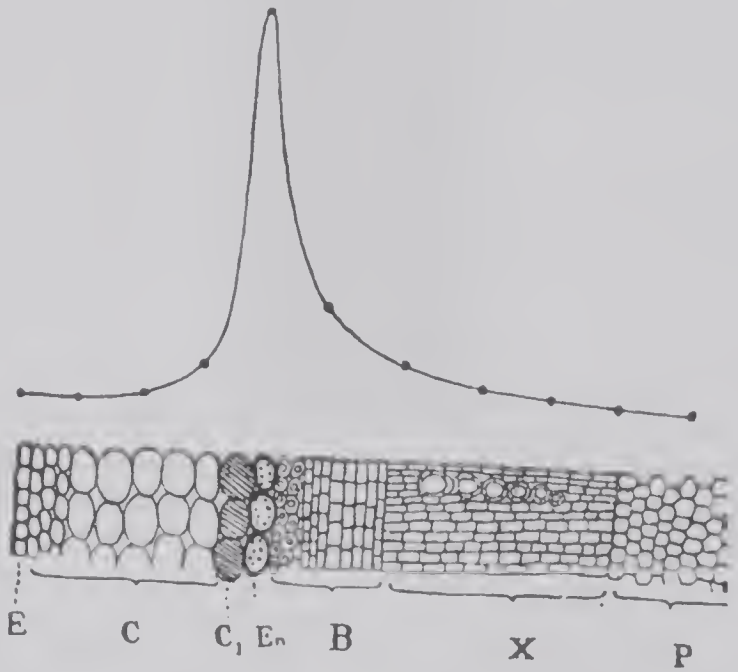

Fig. 25. A section of a *Brassica* petiole showing the relative cellular activity in terms of electromechanical pulsations. The pulsations occur mainly in the inner cortical layer abutting the endodermis. Reproduced from Ref. 31, Fig. 77.

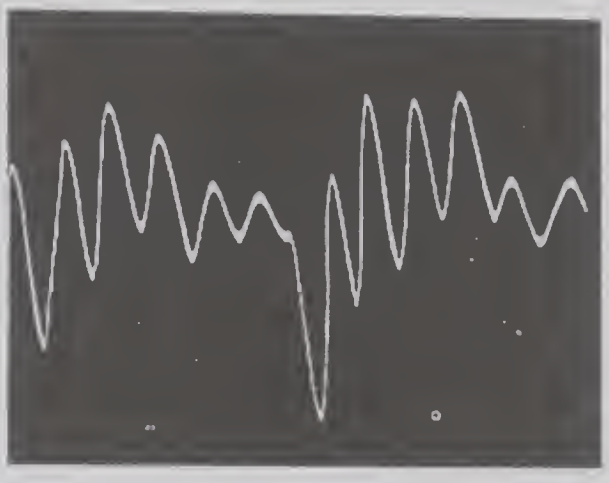

Fig. 26. Periodic groupings of the electrical oscillations in the pulvinus of *Desmodium* (reproduced from Ref. 31, Fig. 69), which accompanied the mechanical oscillations of leaflet position shown in Fig. 17.

Fig. 27. Regular electromechanical pulsations in the cortical cells of *Musa*, the banana. Bose used an Einthoven galvanometer to measure the amplitude of these pulsations in *Nauclea* as ~ 0.4 mV, and lasting ~ 13.5 s. Reproduced from Ref. 31, Fig. 71.

stimulation were produced with an induction coil, with a primary and secondary coil and a "slide" (potentiometer) that could move them precisely together or further apart, generating feeble (0.5–8 μA) currents and strong (100 μA) currents. Currents were measured with a microamperemeter.

Biophytum responded to a feeble stimulating current of about 0.5 μA[27] — too feeble for Bose's tongue to detect,[31] and the *"...sensitiveness of Mimosa to electrical stimulation is high and may exceed that of a human subject..."* [Ref. 27, p. 51].

The major conduction pathway or nerve (established with the electric probe), was proven to be the phloem. Staining with safranin and haemotoxylin revealed two phloem bundles, one internal and one external to the xylem [Ref. 32, p. 34]. The marked difference in the velocities of excitations moving through them led Bose to consider them the equivalent of sensory and motor nerves in the animal. The inner phloem conducted the fast motor impulse, and the outer, the slower sensory impulse [Ref. 32, p. 189]. Thus, Bose proposed, as have plant neurobiologists, that the nervous system of plants contained both afferent (sensory) and efferent (motor) pathways.

A unilateral stimulus was conducted only on the stimulated side. However, when the stimulus was repeated, or increased to a critical intensity, the slow "sensory" impulse was converted to a fast "motor" impulse in the pulvinus. The ascending impulse was converted into a descending "true" excitation after crossing over at the apex of the stem [Ref. 32, pp. 42, 204]. Stimulating the stem produced an electrical signal propagating to the leaves. Stimulating the leaves produced an electrical signal propagating to the stem, and subsequently conducted both up and down, causing other leaves to collapse [Ref. 32, p. 40].

Contemporary plant neurobiologists have located synapses in the actin-enriched cross-walls, particularly of the root transition zone. Bose reasoned that the cross-walls or septa of the phloem sieve tubes represented a synapse as in animal nerves.

The petiole contains four major bundles, which Bose and Das[33] interpreted as four effectors, in four quadrants, each of which determined a characteristic movement. Each bundle or plant-nerve was related to the "handedness" or symmetry of the plant, producing left or right torsions and the sensory response to light.

> *"It is by the particular innervation of the motor organ that the leaf undergoes the purposeful movements by which it places itself at right angles to incident light so as to absorb the largest amount of radiant energy."* [Ref. 33, p. 301]

A non-electrical stimulus (light) applied to the upper half of the leaf produced either of two responses — an increase of turgor (and leaf-lifting) with

moderate or short-lived stimulus, or an abrupt leaf-dropping response (loss of turgor on the lower half) with a strong stimulus.

The former response was associated with turgor increase, expansion of cells, and "galvanometric positivity" (relative hyperpolarization), whilst the latter was a true excitation, a wave of "galvanometric negativity" (relative depolarization), associated with cell contraction and reduction of turgor pressure.

Bose suggested that there was a "synapse" between the pulvinus and the stem. The signal was propagated preferentially from stem to pulvinus, and moderate stimulation of the pulvinus alone was not accompanied by collapse of the leaves [Ref. 31, p. 44].

> *"The typical experiments ... prove that conduction is irreciprocal. They also indicate the existence of a synapsoidal membrane, which by their valve-like action, permit propagation (small to moderate stimulus) in one direction only."* [Ref. 32, p. 48]

The electric signal was a propagated protoplasmic excitation, as in the nerve of an animal [Ref. 32, p. 20]. Signal transmission was arrested by a blocking constant current (two electrodes placed 5 mm apart in between the pulvinus and the point of stimulation, with a constant current maintained between them [Ref. 32, p. 29].

> *"...the contractile cells of the pulvinus ... a wave of excitatory contraction passes from cell-to-cell at a rate slower than the nervous impulse. I distinguished this as cellular propagation of excitation. The phenomenon is not unlike the propagation of a wave of contraction from cell-to-cell in the muscles of the animal heart."* [Ref. 27, p. 91]

The excitatory response in *Mimosa*, was blocked by KCN, $CuSO_4$, sudden application of ice water and chloroform. Strong stimulation (of leaf or stem) in *Mimosa* induced a wave of protoplasmic, electrotonic excitation (depolarization), which was transmitted through the phloem parenchyma to the pulvinus, and there it induced a decrease of turgor, cell contraction, depolarization, and subsequent fall of the leaves. Recovery on the other hand was an expansive phenomenon, involving hyperpolarization, cell expansion, turgor increase and raising of the leaves. Bose viewed the expansive phase as hydraulic, and the contractile, depolarizing phase as nervous and electrical, a true excitation. The two were antagonistic [Ref. 31, p. 255]. Thus there were two forms of signaling, one essentially hydro-mechanical, the other a

true, propagated excitation, and the first could be converted into the second by a strong enough stimulus.

3.6.1.1. *Confirmation of the Mimosa work*

The two forms of electrical signals propagating through the vascular tissue correspond well with:

(i) action potentials, which are transmitted through the phloem as a true form of excitation, and,
(ii) variation or slow-wave potentials, arising as the result of turgor pressure increases in the wake of a hydraulic pressure wave spreading through the xylem.[34]

Are these systems really two nervous systems, sensory and motor, as Bose had proposed? It is now understood that action potentials are genuine self-propagating electrical signals, traveling through the phloem sieve tube/companion cell complexes at about 10 cm s^{-1}, whereas variation or slow-wave potentials are a localized response to a xylem-transmitted hydraulic wave.[80]

The variation potential or slow-wave potential is not evoked electrically. It is graded according to stimulus intensity, and is probably brought about by mechanosensory and/or ligand activated ion channels responding to a hydraulic surge or chemicals in the non-living xylem.[44,45] Similarly, the receptor potential in giant characean cells is a small depolarization brought about by mechanosensory ion channels, and occurs in response to touch stimulus.[115] It is graded according to stimulus intensity. It does not travel from cell-to-cell. However, when a critical depolarization threshold is reached, the receptor potential initiates an action potential, which does travel intercellularly. Reduction of turgor pressure alters the magnitude of the receptor potential for a given stimulus, but not the threshold for the action potential.[113] We have compared the touch response to the turgor-regulating response in salt-tolerant characean cells, where an initial depolarization, due to mechanosensory channels, is transformed into an electrical signal, essentially a long, slow-action potential.[112]

At the level of whole plants, the two types of signal (hydraulic and electrical) play distinct roles, with the hydraulic signal regulating stomatal aperture, and the electrical signal regulating photosynthesis.[62] Thus, it seems

likely that these two types of system, mechanosensory/hydraulic versus excitatory, may indeed be antagonistic, in the fundamental sense that Bose meant.

Many of Bose's findings were confirmed by later researchers. Stimuli such as chilling, heating, cutting, touching, electric stimulus, changes in quality or quantity of light, or external osmolarity can result in action potentials, which are electrotonically transmitted at rates of at least 10–40 mm s^{-1} or much faster, from 500 m s^{-1} to many m s^{-1}.[136] A plant action potential is now understood as a sudden depolarization, where, briefly, a stimulus releases Ca^{2+} to the cytoplasm, activating Cl^- channels and voltage-dependent K^+ channels, resulting in efflux of Cl^- and K^+,[91,138] water efflux, loss of turgor[140] and a transitory contraction of the cell, as measured by laser interferometry in single characean cell.[77,92] Action potentials indeed involve a propagated depolarization, turgor loss and contraction, as described by Bose.

These patterns of Ca^{2+} influx, K^+ and Cl^- efflux, contraction and turgor change are, as Bose had reasoned, the fundamental motifs intrinsic to osmotic machinery that enables plant movements.[69]

An enormous literature is now devoted to *Mimosa pudica* (reviewed in Refs. 114 and 115). Fromm and Eschrich[53–55] demonstrate that excitation does indeed travel in the phloem, that the turgor decrease in the pulvinus is associated with depolarization and expulsion of Cl^- and K^+, as well as a sudden unloading of sucrose from the phloem.[53] The contractile actin-myosin system is indeed involved in the collapse of the leaves, and in the "spontaneous" movements of *Desmodium* (reviewed in Ref. 133). Motor cell movements in *Mimosa* are inhibited by drugs that affect the acto-myosin system involved in cytoplasmic streaming in plants, and in muscle contraction. The cell contraction in *Mimosa* is indeed similar in many ways to muscle contraction.

3.6.2. *All plants possess an electromechanical pulse*

Bose identified electro-mechanical pulsations in *Desmodium*, the "Bon Charal" and reasoned that similar electro-mechanical pulsations are fundamental to all plant life. In contradiction to the (still widely-accepted) Dixon–Joly theory of water transport in plants, Bose proposed that electromechanical pulsations he measured in "ordinary plants" drive the ascent of sap.

The Indian Telegraph Plant *Desmodium* ("Bon Charal" or "forest churl") has a trifoliate leaf, whose two small lateral leaflets make mysterious spontaneous gyrations of regular period. Both stimulus-induced and spontaneous

movements are to be found in *Biophytum*, the "humble roadside weed" that inspired Bose to undertake his researches into plant responsiveness. Finally, Bose measured spontaneous "pulsations" — electro-mechanical oscillations originating in cortical cells of "ordinary" plants making neither stimulus-induced nor spontaneous obvious movements. These included trees such as *Ficus*, *Nauclea*, the mango, monocotyledons including the banana (*Musa*), palms, *Chrysanthemum*, as well as the stolid "quiescent vegetables", including turnip and carrot, with which he had worked in *Response in the Living and in the Non-Living*.

Using the Resonant recorder, Bose plotted the spontaneous leaf-movements made by *Desmodium*. Bose reasoned that the mysterious gyrations of the *Desmodium* leaflet were due to rhythmic alternations between "galvanometric negativity" (relative depolarization) and "galvanometric positivity" (relative hyperpolarization) of pulvinar cell electric potential.

He measured electrical oscillations or "pulsations" of identical period to the changes in cell turgor pressure and leaf movements. "Galvanometric negativity" was coupled with turgor decrease, and leaf downstroke, and "galvanometric positivity" with turgor increase and leaf upstroke.

In winter, he noted, the period of the movements was about four minutes whereas in summer it increased, to one minute. The pulsations were strongly temperature-dependent "*...alternately rendered active or inactive above and below the critical temperature*" [Ref. 31, p. 69], influenced by light-levels, depressed or arrested if turgor pressure was reduced, inhibited by strong or repeated stimulus, arrested by large doses of anesthetic or poisons. Repeated stimuli meant fatiguing and loss of response. After exploring the effects of various wavelengths of visible light, Bose decided to investigate whether plants perceived and responded to radio waves.[30] Using the High Magnification Crescograph, he showed that feeble stimulation accelerated growth in *Mimosa*, whilst strong stimulation retarded it. Interestingly, the *Desmodium* pulsations were arrested by "short-length Hertzian waves"; radio waves, possibly microwaves [Ref. 31, p. 106].

As he had found with the excitatory response in *Mimosa*, the rhythmic leaf movements in *Desmodium* were blocked by KCN, $CuSO_4$, sudden application of ice water and chloroform. A cut in the *Desmodium* stalk prevented the rhythmic leaf movements, but an electric current passing through the pulvinus restored the movements (Fig. 23).

Overall, leaf downstroke in *Desmodium* was due to "*diminution of turgor, contraction, diminished growth rate, negative mechanical response (leaf dropping), electric response of galvanometric negativity (relative depolarization)*".

Leaf upstroke was due to "*increase in turgor, expansion, increased growth rate, positive mechanical response (leaf lifting), electric response of galvanometric positivity (relative hyperpolarization)*".

From these results, Bose [Ref. 13, p. 94) generalized that all forms of significant direct stimulation produced a decrease in turgor pressure, a contraction of cells, a transient diminution of growth rate, a negative mechanical response (such as dropping of leaves) and a "galvanometric negativity" (relative depolarization). Feeble stimuli, on the other hand, produced directly opposite effects, such as an increase of turgor, expansion of cells, transient increase in growth rate. Using the high magnification crescograph, he showed that growth itself was pulsatile in *Desmodium*, corresponding to the patterns of electrical activity.

Today, the tension–cohesion hypothesis proposed by Dixon and Joly in 1894 remains the most widely accepted theory of the ascent of sap. Bose found it inconceivable. The columns of water in the xylem could not sustain the necessary tensile strength, when, surely, air-bubbles would form and impair the cohesion [Ref. 31, p. 2]. Instead, he believed that the ascent of sap depended on the activities of living, pulsating cells. All plants, including trees, had a kind of pulse, a rhythmic electrical oscillation accompanied by turgor increase and decrease.

Using the electric probe, Bose measured pulsations of cortical cells abutting the endodermis [Ref. 31, p. 219] — "*periodic mechanical pulsations corresponding to electric pulsations, as in Desmodium*" [Ref. 31, p. 214]. These pulsations were recorded on a photographic plate driven by clockwork, resulting in a "galvanograph" (Figs. 26 and 27). The "galvanonegative" part of the pulsation was associated with contraction of the cells and a loss of turgor and the "galvanopositive" part with the expansion and swelling of these cells.

As with *Desmodium*, periodic mechanical pulsations, swelling and contracting, were directly coupled with periodic electrical "pulsations". Bose reasoned that fluid was injected into the xylem by expulsive contraction of cortical cells. The xylem was merely a reservoir from which water could be withdrawn or injected according to the conditions, time of day, and temperature [Ref. 31, p. 222].

In a series of extraordinary experiments, Bose connected the electric probe (and reference electrode) to trees as tall as 30 m (the mango, and the Cadamba, *Nauclea*), wiring the signals to a sensitive galvanometer in the laboratory. He used an Einthoven galvanometer to measure the magnitude of the electric oscillations, finding that they were small — about 0.4 to several mV in amplitude in *Nauclea*. The pulsing rate changed from 13.5 s for a

complete pulsation to 3 minutes, with increasing temperature [Ref. 31, p. 214]. The pulsations were feeble on cold mornings, maximal at noon, and changed in amplitude during the course of a day.

If all the cells pulsed together at the same time, there could be no injection of fluid into the xylem. Bose reasoned that there had to be a phase difference of pulsations along the length of the stem. In other words, the pulsations were a sort of peristalsis. By making a permanent electric contact with a stem, and bringing the electric probe progressively closer to it, Bose found a critical distance at which the potential difference between electrodes was maximal and another critical point where no potential difference existed. He reasoned that the distance at which the maximum PD was found corresponded to half the pulse-width. The pulse-width was found to be 100 mm in *Chrysanthemum*, 50 mm in banana, and 40 mm in *Canna* [Ref. 31, p. 225].

He measured similar pulsations in field-grown tomato, vines, and potatoes. The pulse-width increased with sudden irrigation, when warm water was applied to a banana plant, and changed with passage of a constant electric current. The pulsations were enhanced by increased hydrostatic pressure, moderate constant current and increased temperature. They were arrested by a large dose of chloroform (which also arrested the ascent of sap), plasmolysis of the roots, a large drop in temperature, and poisons such as KCN.

Bose concluded "*...any agent affecting the pulsations induced corresponding effects in the ascent of sap...*" [Ref. 31, p. 258]. A succession of periodic hydraulic waves, propagated waves of contraction preceded by waves of expansion, squeezed the sap upwards. The velocity of the ascent of sap was caused by a propagated hydraulic wave of contraction preceded by expansion, squeezing the sap forward.

Bose argued that coupled electrical and mechanical oscillations, protoplasmic contraction and expansion, were a universal mechanism employed by all plants.

> *"...expulsion of sap by cells of the pulvinus on stimulation is an essential part of its motile mechanism, and this applies also to the pulvinule of the leaflet of Desmodium in its "spontaneous oscillation" ... evidence has been accumulated ... that the active expulsion of sap by living cells is an essential part, not only of the mechanisms of movement, but also ... for the distribution of fluid throughout the plant."* [Ref. 31, p. 144]

Presciently, given current discussions of plant synapses as actin-enriched plasmodesmatal regions of cell end-poles, Bose compared a tree to a

bar magnet, with two poles at root and shoot, and an apparently neutral region in between. As the two parts of a divided bar magnet both then show a north and south pole, so it was with the plant, all the way down to the individual pulsating cell. All cells pulsed, and each "*...must exhibit polarity, (one) end absorbing water, (the other) end excreting it.*" [Ref. 31, p. 192]

Furthermore, the polar plant could be divided into quadrants, so that its movements were not only up and down, but also clockwise and anticlockwise. He invented a "torsional recorder" to investigate heliotropic movements, and found that the motor organ had four effectors, one for each of these directions. Plants were exquisitely sensitive to light and temperature, and "*...a beam of light falling on the left flank of the pulvinus of Mimosa induces an anticlockwise torsion (and vice-versa)*" [Ref. 32, p. 156]. Light applied to one side of the stem caused turgor to increase at the diametrically opposite point [Ref. 32, p. 165]. Heliotropic movements in the sunflower *Helianthus*, where the entire petiole was the motor organ, were due to the interplay between contraction and expansion of each side of the plant in relation to the direction of light. In terms of a leaf, "*...the leaf is ... thus adjusted in space by the co-ordinated action of four reflexes, equilibrium being attained when the leaf is perpendicular to the incident light.*" [Ref. 32, p. 172]

3.6.2.1. *Confirmation of the Desmodium work*

Elegant experiments by Antkowiak *et al.*,[6] Antkowiak and Engelmann[4] confirm that the gyration of *Desmodium* leaflets is due to rhythmic changes in the turgor pressure of pulvinar cells, which undergo rhythmic oscillations of membrane potential difference. Using ion-sensitive H^+ and K^+ extracellular microelectrodes as well as intracellular microelectrodes, they showed that the down stroke of the leaflet occurred when the pulvinar motor cells were relatively depolarized, apoplastic K^+ concentration was high, the external PD was negative. The cells contracted, losing turgor. By contrast, the upstroke occurred when the motor cells were hyperpolarized, apoplastic K^+ concentration declined, the external PD was positive, the cell expanded, and turgor pressure increased.[4,6] Like Bose, Antkowiak *et al.*[6] found that increased temperature shortened the period of the oscillations, and an anesthetic (enflurane) abolished the movements.[5] Pulsed radio-frequency fields do transiently alter the amplitude, period and phase of the leaflet rhythms in *Desmodium*.[96]

3.6.2.2. *The existence of a hydro-electrochemical pulse in plants*

In an interesting paper, Holzknecht and Zurcher[70] measured rhythmic variations of electric potential in the bole of trees and linked them convincingly, not only with daily photoperiods, and also, as "stem tides", with lunar periodicities. They attempt to explain how a direct gravitational effect could cause the stem tides by invoking amplification by tidal rhythms of recurrent physiological processes.

Using a very similar experimental set-up to Bose, Gensler and Diaz-Munoz[59] and Gensler and Yan[60] also measured similar electrical pulsations with a palladium electrode inserted in the stem, and a reference palladium electrode in the root zone of tomato plants. A large, stable, and reproducible large potential difference (~ –400 mV) was measured, and superimposed upon it were characteristic potential or time fluctuations, which they called "electrophytograms".[60] The form of these pulsations was directly related to the condition of the plant, its water status, and atmospheric properties. The electrophytograms strongly resemble Bose's galvanographs. Furthermore, the pulsations do seem to be directly related to the ascent of sap. Inserting an electrode in the stem, and a reference electrode in the root zone of cotton plants, these researchers simultaneously measured apoplastic electropotentials and stem diameter before and after rainfall and irrigation. Stems contracted during the day and expanded at night, coupled with a decrease and increase of electropotential. Following irrigation stems expanded and the electropotential immediately dropped.

A coherent explanation for surface potential fluctuations has been recently proposed.[137] The diurnal rhythm in surface membrane potentials represents integration of the metabolic activities of plants on a hydraulic-electrochemical level. In particular, hydraulic changes at the shoot apex prior to initiation of flowers imply a hydro-electrochemical communication between leaves, the shoot, and the root system.[137] Indeed, a specifically-timed electrical signal could substitute for photoperiodic flower induction.[137]

There is one final possible interpretation for some of the small amplitude electrical oscillations Bose measured. Minorsky[84] discusses whether small amplitude low frequency (~ 0.1 to 0.25 mV, 0.1 to 10 Hz) oscillations measured in plants are related to geomagnetic pulsations, with trees acting as antennae. In this case, they are not generated by the tree but rather the tree receives and expresses them. Possibly some of the small amplitude, slow pulsations Bose measured, which were affected by time of day, might fall into this category.

Rhythmic changes in cell volume, brought about by influx and efflux of water, and coupled with the rhythmic changes in cell electric potential difference in *Desmodium*, have been confirmed by many researchers. Mitsuno and Sibaoko[86] found that the pulsations were arrested by inhibition of oxidative phosphorylation, as Bose had found, and by vanadate, which suggested that an electrogenic ion pump rhythmically alters its activity. They also describe the torsion Bose had measured. Electric oscillations are coupled to growth oscillations (or pulses) in roots.[120] In roots, oscillatory patterns of H^+, K^+, Ca^{2+} and Cl^- uptake were measured using a non-invasive ion flux measurement technique.[110] This was the first report of ultradian oscillations in nutrient acquisition, and these authors suggested that the H^+-translocating ATP-ase must operate rhythmically.

3.6.2.3. *The ascent of sap*

Bose's theory of the ascent of sap, which depended on the electro-mechanical pulsations of living cells, embarrassed his colleagues after his death, according to Nandy,[89] because the Dixon–Joly tension–cohesion hypothesis was completely accepted. Today the tension–cohesion hypothesis remains the most widely accepted model of the ascent of sap.

Are there electro-mechanical pulsations associated with the ascent of sap? Water may travel through the xylem in peristaltic waves, according to Laschimke *et al.*,[78] who propose that gas bubbles behave as a hydro-pneumatic system that cyclically stores and releases energy.

In Canny's "Compensating pressure theory" of the ascent of sap, living cells provide compensating pressure, which refills the xylem when the water columns cavitate early in the day. In this theory, the classical measurements of large tensions in the xylem are instead measurements of the compensating pressure, which is matched to increasing rates of transpiration and of embolism. Hydrolysis of starch to sugar in living cells increases osmotic pressure, providing a squeeze, which refills the embolising vessels when necessary. The endodermis in the roots acts as a pump, a one-way valve and a barrier containing the pressure, due to the small size (~5 nm) of pores traversing it. The "Compensating pressure theory" has not received wide acceptance, although it has provoked much valuable debate.[38,40,82]

Under the terms of the current tension–cohesion hypothesis, there is no obvious explanation for the "electrophytograph"-type oscillations in electric potential measured by Bose and contemporary authors.

So, are living cells involved in the ascent of sap, or not?

Canny comments,

> *"...the xylem is not a vulnerable pipeline on the edges of disaster exerting large forces on strong threads of metastable water liable to breakage. It is a self-sustaining pipeline that controls the flow of weak water under varying evaporative demands using at least five levels of homeostatic response and adjustment ... an ultrastable system ... not just a homeostat, but one that responds to environmental changes outside its previous operating experience by changing the parameters of its operation and regaining stability."* [Ref. 35, p. 907]

Bose's rather different model also envisaged the ascent of sap as an ultrastable, adaptable system.

3.6.3. *Like animals, plants have receptors for stimuli, conductors (nerves), which electrically code and propagate the stimulus, and effectors, or terminal motor organs*

Bose maintained that the physiological mechanisms of plants and animals were entirely comparable — that, in today's parlance,[13] plants are neuronal organisms. As Bose wrote:

> *"...the physiological mechanism of the plant is identical with that of the animal"...* [Ref. 37, p. ix]

> *"...All plants and their organs are excitable, the state of excitation being manifested by an electric response of galvanometric negativity (relative depolarization)."* [Ref. 32, p. 95]

> *"It can only be in virtue of a system of nerves that the plant constitutes a single organized whole, each of whose parts is affected by every influence that falls on any other."* [Ref. 27, p. 121]

3.6.4. *Plants have the capacity for learning and remembering, and exhibit a kind of intelligence*

Individuality is one aspect of intelligence, but the mainstream view of plants as passive automata implies a uniformity of responses to environmental stimuli.

Thus, plant physiological experiments routinely pool data and subject them to statistical analysis. This assumption of uniformity is unwarranted, for even clones produce an enormous variety of responses to stimulus.[128] The usual practice of statistically analyzing pooled data in many instances serves to eliminate individual variability that is an aspect of intelligent plant behavior.[128]

Bose considered his experimental plants as individuals, carefully noting their condition and history. Rather than being an obfuscating nuisance, he regarded the changeable environment as being essential for plant behavior to show itself:

> *"...the continuance of normal functions depends on external stimulus ... deprivation of stimulus reduces plants to an atonic condition in which all life-activities are brought to a standstill ... rhythmic activities are maintained ... by stimulus..."* [Ref. 31, p. 245]

As an example, Bose showed that the velocity of the transmitted electrical excitation (action potentials) in *Mimosa* depended on the condition of the plant, being rapid when this was optimum, and low when the plant was in "sub-tonic" condition. Interestingly, excessive stimulation of the plant in "optimum" condition fatigued the response, whilst such stimulation enhanced the response of the "sub-tonic" plant. The dependence on the strength and duration of previous stimulations indicated a form of learning[29]:

> *"A plant carefully protected under glass from outside shocks looks sleek and flourishing, but its higher nervous function is then found to be atrophied. But when a succession of blows is rained on this effete and bloated specimen, the shocks themselves create nervous channels and arouse anew the deteriorated nature..."*

The velocity of electrical (action potential) transmission was modified by "...individual vigor ... temperature, and by the season. In summer, the velocity in thick petioles is 30 mm/s, in winter, as low as 5 mm/s..." [Ref. 32, p. 63]. The age and history of organs powerfully influenced the response:

> *"...It is impossible to dissociate from the consideration of the age of a leaf its previous history as regards the stimulus of sunlight ... the uppermost or youngest leaf of Mimosa (is) pre-optimum and less sensitive ... the sensitiveness ... (reaches a)*

> *maximum as we descend lower ... continuing to descend ... excitability (is) progressively decreased."* [Ref. 27, p. 267]

Poetically, Bose wrote,

> *"...I once did not know that these trees have a life like ours ... they eat and grow ... face poverty, sorrows and suffering. This poverty may ... induce them to steal and rob ... they also help each other, develop friendships, sacrifice their lives for their children..."* [cited in Ref. 89, p. 46]

3.7. Conclusion

A century ago, J. C. Bose proved the fundamental importance of electrical signaling in plants. He did not waver from a position that at the time was outside the boundaries of received mainstream wisdom. In particular, Bose contended that plants have a well-developed nervous system, transmitting excitation through the phloem tissues. All plants possess an electro-mechanical pulse and experienced pulsatile growth. All plants are intelligent, capable of learning, remembering, and responding to their environment in innovative ways: capable, indeed, of anticipating the future and recalling the past. Such concepts have now entered the mainstream, and form a basis for contemporary plant neurobiology. Thus, Sir J. C. Bose should fairly be regarded as a progenitor of this new field of research.

3.8. Postscript

Trees remind us of the physiological, chronobiological cycles and rhythms that so deeply affect us. Many past cultures regarded trees as sacred beings, worshipping them, making sacred trees the basis of an alphabet, as in the Old Irish Celtic Tree Alphabet.[63] A mythic Tree of Life, World Tree, or Cosmic Tree is common to South American, Norse/Germanic, Irish, Chinese, Japanese, Egyptian and numerous other cultures, and is mentioned in the Rig-Veda. According to Zurcher,[138] such similarities cannot easily be explained by direct or cultural influences, and must have as their underlying basis a psycho-spirituality common to humans, perhaps expressed in similar Jungian archetypes.[142]

In Whiteheadian process philosophy, mind cannot be considered a mere product of human brains and neuronal firing, but is inherent in Nature. Mind and matter evolve together, and all living systems are organized by mind.

From this perspective, we may find some fresh inspiration from Bose's philosophy and plant research. As de Quincy[46] writes,

> *"...We need a vision of nature in which all parts of the ecological-cosmological system are innately meaningful, in which sentience or experience is all-pervasive, resulting in a profound sense that the world itself is sacred."*

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The year 2008 marks the 150th birth anniversary of Sir Jagadish Chandra Bose who, at a relatively young age, established himself among the ranks of European scientists during the heyday of colonial rule in India. He was one of those great Indian scientists who helped to introduce western science into India. A physicist, a plant electrophysiologist and one of the first few biophysicists in the world, Sir J C Bose was easily 60 years ahead of his time and much of his research that was ignored during his lifetime is now entering the mainstream. As the inventor of millimeter waves and their generation, transmission and reception, and the first to make a solid state diode, he was the first scientist who convincingly demonstrated that plants possess a nervous system of their own and "feel" pain. J C Bose later spent his life's savings to set up the Institute which carries his name in Calcutta and Darjeeling.

This book covers Bose's life in colonial India, including the general patriotic environment that pervaded at the time and how he became one of the flag bearers of the Bengal Renaissance. It also examines the scientific achievements of this polymath and his contributions to physics and plant electrophysiology, while highlighting his philosophy of life.

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